BOLL WEEVIL SUPPRESSION, MANAGEMENT, AND ELIMINATION TECHNOLOGY

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FOREWORD

Crop losses and control costs make the boll weevil one of the most injurious insects in the United States. Directly and indirectly, it is responsible for 30% of all insecticides used in American agriculture. Increased irrigation and fertilization of cotton and other changes in cotton production technology, beginning in the mid-1940's, increased losses and control costs considerably. In the mid-1950's the development of boll weevil resistance to the commonly used organochlorine insecticides necessitated a change to the more hazardous organophosphorus compounds.

These developments spurred the cotton industry, in 1958, to appeal to Congress for an overall program of research that would adequately deal with an ever-increasing boll weevil problem. Congress directed the Secretary of Agriculture to review the situation and submit a report of research and facility needs to meet the boll weevil problem. The Office of the Secretary appointed a study group to develop the information. The study group's report made two recommendations. The first provided for increasing ongoing research at three of the six locations where Federal research on the boll weevil was underway. The second recommendation provided for the establishment of the Boll Weevil Research Laboratory to concentrate on new approaches to boll weevil control. In 1960, Congress appropriated the necessary funding to implement the two recommendations. The intensified joint research efforts of the cotton industry, State agricultural experiment stations, and the U.S. Department of Agriculture during the next 8 years resulted in the development of a number of extremely promising suppression measures.

These achievements prompted the National Cotton Council of America, in 1969, to appoint a special study committee on boll weevil eradication. This committee, with the help of a technical advisory group, considered actions that should be taken if and when research advanced to the stage that boll weevil eradication might be considered to be technically and operationally feasible. In a meeting of this committee and its advisory group, held on May 6, 1969, reports of progress in research suggested that suppression techniques might already have been developed to the extent that eradication might be achieved. Therefore, the committee felt that a pilot experiment was necessary to test the various suppression measures.

A special subcommittee made numerous onsite visits to various boll weevil infested areas and eventually chose an area in south Mississippi, in cluding adjoining areas of Alabama and Louisiana, for the experiment. The area was chosen because it was regarded as one of the most difficult areas in which to achieve eradication. The Pilot Boll Weevil Eradication Experiment, the largest entomological experiment ever attempted, encompassed a land area of approximately 20,000 square miles, of which approximately 0.2% was planted in cotton. A Technical Guidance Committee was appointed to provide overall guidance for the conduct of the experiment and liaison with the numerous industry, State, and Federal groups involved, and to assess the results of the experiment. Funding was provided by the State of Mississippi, Cotton Incorporated, and the U.S. Department of Agriculture. The experiment began in 1971 and terminated in 1973.

Numerous individuals and groups with strong commitments to the experiment, and many interested individuals not associated with the experiment, felt the need to present the findings in a public forum. The forum was enlarged to include research findings that led to or were associated with the Pilot Boll Weevil Eradication Experiment, assessments of the experimental results, and proposed future strategies in dealing with the boll weevil problem. The forum was organized into two conferences, both of which were presented in Memphis, Tenn. Conference I, entitled "Research on Boll Weevil Suppression and Elimination Technology," was presented February 13–14, 1974, and was sponsored by the U.S. Department of Agriculture and State agricultural experiment stations, cooperative extension services, and departments of agriculture of the Southern Region, in cooperation with Cotton Incorporated and the National Cotton Council of America. Conference II, entitled "Boll Weevil Management and Elimination Strategies," was presented February 15, 1974, and was sponsored by the National Cotton Council of America in cooperation with Cotton Incorporated and the land-grant universities in boll weevil infested States. The program committee members were F. J. Boyd, supervisory entomologist, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Mississippi State, Miss.; F. A. Harris, professor of entomology, Mississippi State University, Mississippi State, Miss.; R. C. Riley, principal entomologist, Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C.; George A. Slater, vice president, Agricultural Research, Cotton Incorporated, Raleigh, N.C.; J. Ritchie Smith, director, Technical Research Service, National Cotton Council of America, Memphis, Tenn.; and D. F. Young, Jr., leader, Extension Entomology, Mississippi State, Miss.

All of the presentations that were made available to the conference coordinator and the recorded final discussion are included in this volume.

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HISTORY OF THE BOLL WEEVIL PROBLEM

By William H. Cross[1]

Before the 1890's we did not know there was a boll weevil. Pre-Columbian Indians in Central America and Mexico may have known of its damaging cotton, but we can find little evidence of it except for an adult specimen found in a *Gossypium hirsutum* L. boll fragment from Oaxaca, Mexico, in diggings dated 900 A.D. If Spanish Americans had boll weevil problems before the middle 1800's no record has been seen. The earliest known record of the boll weevil did not even connect it with cotton. It was described by C. H. Boheman in 1843 as *Anthonomus grandis* from an adult collected 1831–1835, and labeled "Veracruz" with no host record.

But in 1893, C. H. DeRyee, a distressed citizen of Corpus Christi, Tex., wrote the U.S. Department of Agriculture describing difficulties of the farmers in the Brownsville area, who were confronted with a new cotton pest. He described the late season crop as being heavily damaged by an insect laying eggs in squares and small bolls. By 1894, six South Texas counties were infested by this pest, subsequently identified as *Anthonomus grandis.* Leland O. Howard, chief of U.S. Department of Agriculture's former Division of Entomology, dispatched C. H. Tyler Townsend to examine infested territories in this area and in adjacent areas in Mexico. He soon reported on the dangers involved in allowing the boll weevil to move into the cotton-growing South. He looked for mechanical explanations for the appearance of the boll weevil in Texas, but was unaware of its capacity for flying long distances. In Monclova, Coahuila, Mexico, he found evidence that the boll weevil had damaged cultivated cotton there as early as the 1850's.

As the boll weevil spread into Texas, various remedies were suggested. The U.S. Department of Agriculture early recommended stalk destruction during the fall to deprive the weevil of his food supply. Many weevil catching machines were proposed. One was mule-drawn with revolving brooms which shook weevils into attached pans, another picked up and destroyed fallen squares, and another blew fine, powdered poison on the plants. Farmers tried to destroy the pest with ashes, lime, london purple, and paris green. The one remedy that Townsend recommended was poisoned molasses. A number of communities promoted hand picking of adult weevils and set up funds to pay for them, offering from 10¢ to 50¢ per 100. A Waelder, Tex., merchants' fund to pay 15¢ per 100 was rapidly expended when 15,000 to 35,000 per day were brought in. As far back as 1903, early maturing varieties of cotton were employed to make a crop before seasonal infestations reached damaging levels.

It was commonly thought that the boll weevil would reach a northern limit. In 1903 two professors in Louisiana promoted a plan to establish a noncotton belt along Louisiana's western boundary to prevent the weevil's entry into their State. But in 1904 weevils appeared in Louisiana, and by then 32% of U.S. cotton was infested. The boll weevil was rapidly becoming U.S. agriculture's major pest. In this year, demonstration programs to educate the southern farmer in boll weevil control were begun.

The march of the weevil had reached to within a few miles of the southwest corner of Mississippi by 1906. Some proposed that the Mississippi River was an adequate barrier to its spread. But then on September 20, 1907, W. D. Hunter, visiting at Natchez, found that the weevil had crossed the river at a number of points. The subsequent spread of the weevil took it to the last of the Southeast's cotton on the shores of Virginia by 1922. More recent extensions of the boll weevil's range occurred in 1953, when the Presidio, Tex., area was first reported infested from Mexico populations to the south, and in 1961, when a notable spread into the Texas High Plains was observed. These latter reports warned of the weevil's possible adaptation to dryer western areas.

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As already mentioned, early emphasis was placed on mechanical and cultural control. Even in 1910 the basic biology of the boll weevil was well understood, and its more important natural enemies were known. But interest in biological studies and biological control diminished in the 1930's when calcium arsenate was first used as an effective control of the boll weevil. Later, in the mid-1940's, the highly persistent arsenate was replaced by a combination of DDT and toxaphene and related compounds. When DDT was banned in 1972 by the Environmental Protection Agency because of its persistence, it was fortunate that organophosphate compounds such as methyl parathion, Guthion, and malathion were available. But the ever-present threat of the weevil's developing resistance to insecticides and the concurrent price we pay in killing off predators and parasites of other cotton insects (especially the bollworm and the tobacco budworm) have led to the recent emphasis on an integrated program against the boll weevil.

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ECONOMIC IMPACT OF THE BOLL WEEVIL

By Robert R. Coker[1]

A great deal of time, energy, and money has been spent on the boll weevil over the past decades, and I think most people concerned with cotton production agree that we cannot afford this pest any longer.

When the boll weevil moved into our section of South Carolina in 1920, we lost 31% of our crop. Since that time, we have found many ways to fight the pest, but losses have continued despite the use of all the suppression measures that have been developed.

In our section, as in all other weevil problem areas, we rely mainly on insecticides to keep the pest from taking our crop. Year after year on our farm, we make from 15 to 20 insecticide applications. Even so, the boll weevil adds 7¢ to 10¢ a pound to our cotton production cost. The cost varies from place to place, but it averages about 3½¢ to 4¢ a pound across the boll weevil belt.

Crop losses and control costs alone range from \$200 million to \$300 million every year. More insecticides are applied for boll weevil control than for control of any other crop insect. The U.S. Department of Agriculture estimates that one-third of all insecticide used in this country is required because of the boll weevil problem. The cotton industry has run up a \$12 billion bill since the insect entered this country from Mexico in 1892.

From 1909 through 1954, the U.S. Department of Agriculture made annual estimates of crop loss attributed to the boll weevil. By projecting these loss figures through 1971, we find that for the period 1909 through 1971, the total loss of cotton and cottonseed directly attributable to the boll weevil amounted to 85.4 million bales of cotton and 36.3 million tons of seed. Based on farm prices during this 63-year period, the lint and cottonseed lost amounted to more than \$11 billion, or an annual average of \$175 million.

The 36.3 million tons of cottonseed would have produced 1½ billion gal of cottonseed oil, and would have required 190,000 railroad tank cars to transport it. Domestic disappearance of food fats and oil is nearly 52.7 lb per capita annually. At this rate, the cottonseed oil lost would have provided the total food fats and oil requirements for the total population of the United States for an entire year. The cottonseed lost would have produced 16½ million tons of high protein meal, and 9 million tons of hulls. Given the fact that 93 lb of cottonseed meal used with the proper amount of silage will produce 100 lb of beef, the meal that was lost could have produced 169 lb of meat for every man, woman, and child in the United States.

The 85.4 million bales of cotton destroyed between 1909 and 1971, if placed end to end, would extend in a straight line 72,799 mi long, and would reach around the earth at the equator almost three times. It would reach approximately one-third the distance from the earth to the moon.

From one bale of cotton can be produced 640 long-sleeved, combed-cotton shirts, 3,408 medium-weight diapers, or 5,485 handkerchiefs. According to the 1970 census, there are 71.5 million males in the United States 14 years or older. The cotton lost to the boll weevil, if made into shirts, would have provided these individuals with 764 shirts each. Made into diapers, it would have provided each of the 8 million children in the United States under 2 years old with 36,000 diapers each. The same cotton made into handkerchiefs would have provided 130 for each of the 3.6 billion inhabitants of this planet.

These are just the direct losses. Indirect costs attributable to the boll weevil are also great. Ef-

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forts to control the boll weevil create other costly insect problems. For example, insecticide applications directed against the weevil eliminate many beneficial insects and bring on increased bollworm infestations and population explosions of other cotton pests. These mushrooming problems often require the use of still more insecticide, and the expenditure of still more money.

There are other costs that are difficult to gage. When a farmer runs a spray rig over his fields, for example, in addition to chemical costs and the cost of the fuel and labor, he further compacts the soil. It costs something to work that soil to break up the cumulative effect of many compactions, some of them the result of insecticide application, and soil compaction hurts cotton yields and quality.

Other indirect costs include machinery wear and to some extent even machinery investment, all made necessary by the presence of the boll weevil.

Consider, too, all of the pickup trucks running back and forth to keep spray rigs running and to transport insecticides to the fields. Every mile so spent is money paid to the boll weevil.

Massive programs of containment add their toll, too, to the weevil's price tag, and yet the pest spreads except where costly vigilance guards the weevil's path to new territory. If the boll weevil is allowed to remain in U.S. cottonfields it already occupies, it will continue to pose dangers to the irrigated West. Scientists believe that the future spread of the insect to the West is virtually certain unless something is done to stop it. If it is allowed to move west, it would of course add more farms, more States, and more dollars to its impact.

Now is the time to act, unless we want to let ourselves be locked into a problem which has grown past the point that we can afford.

In fighting the boll weevil and trying to protect our crops against its ravages, we have gradually built a workable technology. There were the days of paris green, of course—a futile exercise that was more costly perhaps in its economic context than the most sophisticated methods of crop protection today. We used calcium arsenate and killed many boll weevils, but we also created aphid problems, and began to see what a sharp fulcrum nature has under her balances, where a tiny move on one end of the seesaw causes a corresponding shift on the other end. Scientists later gave us the chlorinated hydrocarbons and they worked against the weevil —until the insect began to develop resistance.

Today, because of resistance, problems with nontarget insects, environmental concern, and Government regulations which have removed some of our most effective chemicals from our arsenal, we are left with only the organophosphorus compounds and the very real possibility that boll weevils may develop resistance to those chemicals. If we lose our present chemical weapons against the weevil, the economic impact on the grower can easily be a 50% loss of his crop in a year's time.

Another phase of economic considerations in the boll weevil problem is Government appropriations. The first Federal money for boll weevil investigations was a $2,000 appropriation in 1896. During the next 55 years—down to 1950—the total amount spent by the Federal Government on boll weevil research was $3,207,697. In this same period, the weevil caused losses of more than $10 billion. In the next 9 years, 1951 through 1959, direct Federal research and Federal grants to State experiment stations totaled $1,312,842. In 1960, Congress appropriated $1,-100,000 to build the Boll Weevil Research Laboratory (BWRL) at State College, Miss. Further appropriations included $165,000 for staffing the BWRL; $40,000 each for existing labs in South Carolina and Texas; $32,000 for the Baton Rouge Cotton Insect Research Laboratory; and an additional $125,000 to build new facilities at the Florence, S.C., laboratory. Since the BWRL has been in operation, it has been budgeted at around $800,000 to $1 million each year. The Pilot Boll Weevil Eradication Experiment (PBWEE) cost about $5 million which came from the U.S. Department of Agriculture, Cotton Incorporated, and State of Mississippi funds.

All this means that more than $21 million in Federal, State, and cotton industry funds have been spent exclusively for boll weevil eradication since the BWRL was put into operation in 1961. This is a sizable, yet very wise investment, in the opinion of many in Government and in the cotton industry. But it will be largely wasted unless the elimination program proceeds. If the boll weevil is allowed to continue its ravages, much of this investment will have gone into a mere holding action.

THE BOLL WEEVIL AS A KEY PEST

By D. G. Bottrell[1]

Smith and van den Bosch (1967) defined key pests as "serious, perennially occurring, persistent species that dominate control practices. In the absence of deliberate control by man, the pest populations usually remain above economic-injury levels." In other words, these are the stubborn pests that appear nearly every year and, unless controlled, inflict serious economic losses. By Smith's and van den Bosch's definition, the boll weevil, *Anthonomus grandis* Boheman, was a key pest in approximately 52% of the cotton grown in the United States in 1972, seriously occurring in 7.3 million acres out of a total of 14 million (Thomas 1974). It was a marginal pest on an additional 12% of the 1972 crop, or 1.7 million acres.

Though in the literal sense the boll weevil is a key pest in only about half of the U.S. cotton acreage, its impact on cotton and the surrounding environment amounts to a "key problem" confronting the American people. Undoubtedly, the species is the most costly insect pest of cotton, causing estimated yield losses of 8% annually; in addition, it is the target for approximately 30% of all insecticides used in American agriculture (National Cotton Research Task Force 1973). Much of this insecticide treatment results in destruction of natural enemies of other cotton pests, and this leads to further insect losses, control costs, and contamination of the environment.

There can be no doubt that the application of insecticides for boll weevil control has been a major factor in the continuation of profitable cotton production. It has been shown many times that, left uncontrolled, the boll weevil is often capable of inflicting nearly complete cotton losses.

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In spite of the positive benefits gained from the use of insecticides against the boll weevil, however, quite serious problems have resulted from complete reliance on insecticides. Walker and Niles (1971) describe the chronology of these problems, which began shortly after World War II, when chlorinated hydrocarbons were introduced. At first, these materials were highly effective against the boll weevil. Control was spectacular and yields were greatly increased as a result. The producers became totally reliant on these materials to control the pest.

The new insecticides allowed the planting of indeterminate cotton varieties which produced fruit over a long period in the season without interference from boll weevil attack. Producers no longer needed to plant early-maturing cotton varieties, which previously had been planted in attempt to mature the crop early enough in the season to escape damage by high population densities of weevils which developed later in the year. Also, early stalk destruction was no longer necessary, though previously the practice had been accepted as a means to decrease the overwintering potential of weevil populations by eliminating cotton as a food source.

Thus the new insecticides not only protected cotton from depredation by the boll weevil, but they also permitted the development of a new cotton production system. Early maturing varieties were replaced with indeterminate varieties. The practice of early stalk destruction was discontinued. Also, since insecticides allowed for greater yielding potential, producers could afford to fertilize and irrigate their cotton. This new production system boosted the cotton yields, which resulted in greater profits, which, in turn, justified the use of even greater quantities of insecticides to combat the boll weevil. The new production system also created an environment which favored a greater potential for boll weevil population increase, but this potential was masked by the insecticide treatments.

By the mid-1950's, however, it became evident that the chlorinated hydrocarbon insecticides, and the new cotton production system which they permitted, were not without their limitations. The boll weevil became resistant to these insecticides, and resistance soon spread throughout the insect's range (Eden 1968). Also, the bollworm, *Heliothis zea* (Boddie), and tobacco budworm, *H. virescens* (F.), soon became resistant to the materials (Adkisson and Nemec 1966). The boll weevil and these other pests soon flourished on the lush growing cotton.

To overcome the problems of resistance, producers switched to organophosphorus materials. These materials, although highly effective, had to be applied more frequently than the chlorinated hydrocarbons because of their shorter residual life. The increased frequency of application imposed a greater insecticide load on the cotton ecosystem. It also caused almost total destruction of populations of natural arthropod enemies. The unfortunate result has been the outbreak of potential pests such as bollworms and tobacco budworms. These pests have inflicted more damage than the boll weevil, for which the insecticides were initially applied. In many parts of Texas, for example, the budworm is resistant to all insecticides registered for use on cotton (Adkisson 1969). It has inflicted disastrous damage on cotton in the Lower Rio Grande Valley in spite of the fact that cotton in the area has been treated 20 times or more annually with methyl parathion (Adkisson 1973).

Concurrently with the appearance in the 1950's of strains of boll weevils resistant to chlorinated hydrocarbons, the species continued to increase its range in the United States. Damaging infestations of the insect occurred near Presidio in the arid Trans-Pecos area of Texas in the nearly 1950's (Robertson 1957). This was more than 200 mi west of previously detected damaging infestations. At about the same time the boll weevil invaded the Presidio area, it also began to establish itself in previously uninfested areas to the north and northwest in Texas. In the early 1950's, it became a new pest in the northern Texas Rolling Plains. In the late 1950's and early 1960's, the pest invaded the Texas High Plains and caused severe economic damage to cotton along the eastern fringe areas (Bottrell et al. 1972). Finally, the thurberia boll weevil broke out on cotton in southern Arizona in mid-1960's (Fye 1968).

In the past 25 years, the boll weevil also has increased its range in countries other than the United States (Cross 1973). The species has spread into Venezuela, Colombia, and Hispaniola (Burke 1968).

Why is it that the boll weevil, an insect alien to the United States until as recent as the late 1800's, when it entered from Mexico, has established itself so firmly in American agriculture?

The boll weevil is no different than many other key pests, especially those which entered this country from other world regions. The weevil is merely one of the many key pests of American agriculture possessing numerous "built in" defense mechanisms to prevent its extinction. It also is merely one of many key pests possessing "built in" offense mechanisms to insure its extension over and beyond the present pest situation. Let us examine some of the biological mechanisms responsible for the ever-growing weevil problem in the United States.

1. *The insect's genetic plasticity and its ability to continually adapt to new environments.*—The boll weevil's spread and establishment in the United States over the past 80 years in themselves should be proof of the species' tremendous plasticity. In the United States alone, the species has successfully adapted to environments ranging from near-tropical to arid, cold-winter situations. The development of resistance to the hydrochlorinated insecticides should be further proof of the insect's ability to successfully adapt to wide-ranging and even hostile environments. There is no reason whatsoever to suspect that the boll weevil cannot someday extend its range into every part of the United States where cotton is grown. Further, there is no reason to suspect that the pest will not eventually become resistant to the organophosphorus compounds.

2. *The lack of highly effective native biological control agents.*—As is often the case with introduced pests, the boll weevil has no highly effective natural enemies which regulate its population density. There are numerous natural enemies which attack the boll weevil (refer Bottrell, "Biological Control Agents of the Boll Weevil," this volume) and some of these induce a high level of population mortality under certain situations. In general, however, natural

constraints on the weevil populations by parasites, pathogens, and predators are not sufficient by themselves to prevent the pest from causing economic damage.

3. *High reproductive potential and faculative diapause.*—There are several reproductive generations (two to four) of boll weevils each year, and one or two diapausing generations as well. Numerous entomologists have calculated that one pair of reproductive weevils in the spring could theoretically result in several million weevils late in the season. Of course, because of various environmental constraints, this rate of increase is never observed. Nevertheless, the reproductive potential in the boll weevil is extremely high, varying from 2- to 40-fold per generation under natural conditions in cotton without insecticide treatment (Cross 1973). Walker (1966) observed that the rate of increase in a natural population of boll weevils was inversely related to the population density; i.e., proportionately higher rates were observed in smaller populations. Presumably, the larger populations limit square production, which limits the oviposition sites.

Diapause, first observed in boll weevil by Brazzel and Newsom (1959) is a phenomenon occurring in the adult stage that bridges the pest between cotton seasons. This winter survival mechanism insures that certain members of a population which enter hibernating habitat in fall will emerge in spring and repopulate cotton in the area. Neither the entry of a population of weevils into diapause nor their emergence from this state is synchronized to an exact time of the year. That is, the appearance of diapause extends over a period of several weeks in the late summer and fall, and emergence from it extends over a comparable period in spring and summer. This mechanism in the species allows for wide adaptation to new environments and insures continual survival in one area.

4. *Great dispersal powers.*—The rapid extension of the boll weevil's range during its first few years in North America as well as the more recent extensions described above have come about largely as a result of innate migration and port by man. Long-range dispersal or migration dispersal tendencies and not accidental transoccurs during the late season and has been responsible for the weevil's expanding many miles into previously uninfested cotton in just one year (Bottrell et al. 1972). This behavioral characteristic, which occurs in both reproductive and diapausing weevils, is probably the single most powerful survival trait the boll weevil possess. It allows the insect to continually invade new territories and to reinvade old territories temporarily ridded of the species.

The purpose of these conferences is to review the basic and applied knowledge on the boll weevil and to explore the present feasibility of eliminating or eradicating the pest with available technology. Undoubtedly, costs which have been estimated as necessary to achieve this ambitious task are only nominal compared to the costs the pest has inflicted on American agriculture. Achievement of the goal of complete elimination of the pest from the United States would be a major contribution to the American people.

However, what if anything less than complete elimination is achieved after an "all out" war has been implemented against the pest throughout the Cotton Belt? That is, what kind of a boll weevil pest-situation would exist if economic weevil damage was stopped at the end of the proposed beltwide attempt, but the insect still survived in low numbers? What prophylaxis would then be required to deal with the situation? I am of the opinion that promoters of the beltwide elimination program are evading such questions.

Because there is ample optimism concerning the complete elimination of boll weevil from the United States, I would like to inject a few words of pessimism, perhaps realism, about the consequences entomologists and the American people may have to face if less than complete elimination is achieved.

Presently, the boll weevil is a genuine monster to deal with. Although organophosphorus insecticides can be used effectively against the pest, both on reproductive and reproduction-diapause schedules, they must be applied at frequent intervals to effect good control. But in due course, the applications almost invariably disrupt the natural biological control of *Heliothis* and other potential pests of cotton. It hardly seems necessary to discuss the problems arising once this disruption occurs, since most of us are familiar with the economic disasters potential in the appearance of the resistant tobacco budworm in cotton (Adkisson 1969).

What, then, would be the expected behavior of

Heliothis in an all-out beltwide elimination attempt which would rely on more insecticide applications than those now being used? Isn't it possible that the boll weevil applications would be counteractive? That is, would they not possibly create a resistant *Heliothis*, a problem far more serious than that of the boll weevil? Furthermore, does it not appear highly likely that the severe insecticide pressure on the weevil throughout its complete range in the United States, which an elimination effort would require, would increase the chances of an organophosphorus-resistant strain appearing in the U.S. population? True, the pest is currently under tremendous selection pressure in many areas of the United States. But we also must remember that much weevil-infested cotton in the United States is currently not being treated at all, which means that selection pressure across the Cotton Belt would be greatly increased during the insecticidal phases of an eradication attempt.

There is no doubt that complete beltwide elimination of the boll weevil as a key pest would be a giant stride for North American agriculture. On the other hand, a beltwide attempt at elimination which was anything less than completely successful could result in the fabrication of an organophosphorus-resistant "superduper" pest.

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SEASONAL DEVELOPMENT OF THE BOLL WEEVIL

By Charles Lincoln[1]

Boll weevil development, i.e., population increase, requires food and favorable weather. Cotton squares are the preferred food for rapid development of the immature stages and high rates of egg-laying by the adults. The rate of development in bolls is somewhat slower and bolls become unsuitable for egg deposition at about 16 days of age.

A mean temperature in the low 80's is optimum for rapid weevil population increase. Interestingly enough, the mean July temperature throughout the U.S. boll weevil belt ranges from 78° to 86° F, optimum for the boll weevil.

The immature stages (egg, larva, pupa, and callow adult) are passed in 2 weeks in squares at optimum temperatures. The preoviposition period requires 5 or 6 days. This gives a minimum generation time of 2½ to 3 weeks.

The egg-laying period lasts for 3 to 6 weeks—as long or longer than the developmental period. Some 250 to 300 eggs are laid by a female weevil.

Infested squares turn yellow, flare, and usually drop to the ground. Here they may be exposed to fatal high temperatures, commonly referred to as "sun kill." The squares detached from the plant are subject to dessication, which may prove fatal to the larvae and pupae. The combination of hot, dry weather is the most common mortality factor limiting the rate of increase of boll weevil populations during summer when food is abundant.

Weevils starve in the absence of food except when they are in a state of reproductive diapause. Weevils in diapause survive from one crop year to the next.

Complete description of seasonal population development in fruiting cotton is complex. Diapausing boll weevils enter the following crop over a long time period, often a month after fruiting has begun. The egg-laying period is usually longer than the developmental period, giving a complete overlap of generations. Weather affects developmental rates, egg-laying, and mortality. Weevils enter diapause, removing them from the reproducing population.

A practical alternative to complete analysis of this complex interplay of factors is simply to measure populations by field scouting. Boll weevil populations increase 2.5-fold weekly under favorable conditions. Hot, dry weather reduces this rate, often drastically. As the fruit load shifts from mostly squares to mostly bolls, the increase rate slows down.

A given field may provide abundant squares for weevil development for 6 to 9 weeks, depending on soil fertility, variety, weather, irrigation, etc. At 2.5-fold rate of weekly increase, the seasonal population increase would be 100-fold in 6 weeks and 1,600-fold in 9 weeks.

A boll weevil control program, as presently practiced, utilizes the actual rate of increase in deciding whether or not to apply insecticides. In a boll weevil elimination program, it would be prudent to assume the maximum rate of increase.

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DIAPAUSE AS IT RELATES TO THE BOLL WEEVIL
Anthonomus grandis Boheman

By J. R. Phillips[1]

In the initial paper describing a diapausing boll weevil[2] the following criteria were used: (1) Cessation of gametogenesis, (2) atrophy of gonads, (3) increase in fat body, (4) decrease in the respiratory rate, and (5) decrease in water content. Since this paper, most researchers working in the area of boll weevil diapause have ceased using decreased respiratory rate and decreased water content as determining factors and equate diapause with an animal that is fat and has atrophied gonads. I feel that this is a serious mistake, since both reproductive and nonreproductive weevils with increased body fat have been collected in midsummer. Conversely, nonfat weevils have been taken that included both reproductive and nonreproductive weevils. In most cases, however, the majority of the questionable individuals were females.

Based on the present status of data in Arkansas, it is my opinion that three distinct female types can be identified with diapause: (1) An individual that emerges in diapause, fat, and with atrophied gonads (this weevil probably does little or no feeding), (2) an individual that emerges and feeds, but egg resorption occurs before any oviposition occurs, and (3) an individual that emerges, feeds, and oviposits some before egg resorption occurs. The last two types are dependent upon being able to feed before the fat body is developed, and in this sense are dependent upon food's being available before they can enter diapause.

Certain environmental stimuli have been reported to be involved in the initiation of the diapause photoperiod. There are many papers dealing with the subject. Generally, the concensus is that short days (10–11 h of light) induce diapause, and long days (13–14 h of light) inhibit diapause. Other stimuli reported to induce diapause include exposure to night temperatures of 10° C during the adult stage, boll feeding during the adult stage, limitation of the quantity of squares (flowerbuds) during the adult stage, immature development in bolls, and plant maturity.

The importance of the photoperiod in the diapause phenomenon is well recognized. It provides the animal with a stimulus that recurs every year with mathematical precision, and is certainly a reliable indicator of seasons. It follows that with decreasing photoperiod, cool temperatures, and the food implication, a boll weevil could be expected to diapause sometime after July 30. There is ample evidence in the literature to support this assumption.

In data collected during 1973 in two locations in Arkansas, we found that as many as 80% of the P_1 females entered diapause at both locations. It was not until midsummer that female diapause began to decline. During this same time period only a few males entered diapause under the same conditions. Weevils used in this study were collected as immatures in squares and held in an open-air insectary until adult emergence. Adults were fed both squares and synthetic diet with essentially no differences in the manifestation of diapause characteristics. If early diapause of this magnitude occurs frequently, we certainly must determine the behavior and fate of these weevils.

The host is certainly implicated in these findings. We have collected additional data during the past 2 years that further support the fact that the condition of the cotton plant is very much a stimulus contributing to the onset or inhibition of diapause in the boll weevil.

We have conducted many tests to determine the influence of plant condition on diapause. In brief summary of our data, it can be said that generally any condition that induces stress on the cotton plant may cause an increase in diapause. This increase can and will occur under photoperiod and temperature conditions that normally inhibit diapause. Auxin inhibitors and plant maturity will also cause an increase in diapause response. This was found to be especially true in fast-fruiting, early-maturing varieties

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[2] Brazzel, J. R., and Newsom, L. D. 1959. Diapause in *Anthonomus grandis* Boh. J. Econ. Entomol. 52: 603–611.

supplied by Texas A&M University. (See tables 1–6.)

These data support the assumption that the weevil in its northward movement has adapted to photoperiod as an indicator of season but has also retained the capacity to "read" its host, no doubt a characteristic that evolved around the occurrence of dry- and wet-season conditions that exist south of the border. Thus, we seem to have an aestival diapause weevil (responding to host) and a hibernal diapausing weevil (responding to photoperiod).

TABLE 1.—*Boll weevil diapause as influenced by host plant maturity, Newport, 1972*

Entry	Fruiting pattern	Percent diapause[1]		
		Males	Females	Total
66–M–10	Past peak	14.29	61.11	33
1x6–56	Past peak	15.79	57.14	40
Mean		15.15	59.38	37
Other entries	Increasing to peak	12.96	23.58	18.6

[1] Weevils were collected as 7- to 10-day-old immatures on July 27, 1972, reared to 7-day-old adults, then dissected.

TABLE 2.—*Boll weevil diapause response to adjusted vs. normal fruiting levels, Arkugo #1 cotton, Altheimer*

Date immatures collected	Date of dissection[1]	Percent diapause	
		Adjusted fruiting[2]	Normal fruiting
July 25	Aug. 20	12.1	14.1
Aug. 15	Aug. 30	40.0	61.5
Aug. 22	Sept. 10	51.7	63.9
Aug. 29	Oct. 4	57.9	75.0

[1] Dissected as 7-day-old adults.
[2] 75,000 squares/acre.

TABLE 3.—*Diapause in progeny of overwintered weevils*

Location and date immatures collected	Date dissected	Percent diapause		
		Males	Females	Total
Newport:				
July 5	July 25	0	92.9	46.4
July 10–11	July 27	0	59.5	33.3
July 18	Aug. 3	2.4	21.2	10.7
Altheimer:				
June 29–July 2	July 23	2.6	73.3	40.5
July 2–6	July 25	0	46.2	23.1
July 9–13	July 26	0	39.0	18.0

TABLE 4.—*Diapause on cotton treated with an antiauxin, DPX–2801*

Date	Mean, all treatments		Checks	
	Squares per acre (1,000's)	Diapause (%)	Squares per acre (1,000's)	Diapause (%)
July 25 treatment:				
July 25	219	....	244	....
Aug. 2	160	9.4	166	12.8
Aug. 9	197	18.1	212	28.1
Aug. 16	142	44.7	218	24.0
Aug. 7 treatment:				
Aug. 7	179	....	213	....
Aug. 16	178	....	212	....
Aug. 23	125	32.5	203	24.0
Aug. 29	99	63.5	186	59.7
Sept. 13	6	76.1	34	63.6

TABLE 5.—*Seasonal diapause in boll weevils, Newport, 1973*

Collection date	Dissection date	Percent diapause	
		Males	Females
July 4	July 23	0	92.9
July 11	July 31	0	59.5
July 18	Aug. 9	0	13.2
July 25	Aug. 16	10.5	17.6
Aug. 1	Aug. 21	0	28.6
Aug. 8	Aug. 29	2.3	20.7
Aug. 15	Sept. 3	22.6	29.2
Aug. 22	Sept. 13	66.1	67.4
Aug. 29	Sept. 17	44.6	60.6
Sept. 5	Sept. 29	56.0	61.7
Sept. 12	Oct. 5	59.4	76.8
Sept. 19	Oct. 9	79.6	88.8
Sept. 26	Oct. 15	68.9	64.7

TABLE 6.—*Seasonal diapause in boll weevils, Altheimer, 1973*

Collection date	Dissection date	Percent diapause	
		Males	Females
June 27	July 23	2.6	73.3
July 4	July 22	0	54.5
July 11	July 27	8.3	14.3
July 18	Aug. 2	3.5	23.1
July 25	Aug. 15	1.6	29.7
Aug. 8	Aug. 21	9.2	34.4
Aug. 15	Aug. 30	21.5	35.7
Aug. 22	Sept. 11	50.8	58.2
Aug. 29	Sept. 17	44.1	83.4
Sept. 5	Sept. 27	75.9	73.3

Cienfuegosia drummondii AS A HOST OF THE BOLL WEEVIL, *Anthonomus grandis*, IN SOUTH TEXAS[1]

By Horace R. Burke and Wayne E. Clark[2]

The first report involving association of the boll weevil, *Anthonomus grandis* Boheman, with plants of the genus *Cienfuegosia* was made by Szumkowski (1952) who observed the weevil developing on *Cienfuegosia affinis* (H.B.K.) Hochr. in Venezuela. Cross et al. (1975) summarize the known association of the boll weevil with species of *Cienfuegosia* and include the first record of reproduction on *C. rosei* Fryx. near Tehuantepec, Oaxaca, Mexico. Lukefahr and Martin (1962) later reported that *Cienfuegosia drummondii* (A. Gray) Lewt. served as a host of the boll weevil in South Texas. The latter authors found the plant to be fairly widespread in the middle and lower coastal areas of Texas, and observed infestations of weevils at several localities.

Fryxell (1969) conducted a comprehensive taxonomic study of the genus *Cienfuegosia* and mentioned some interesting points concerning the distribution of *C. drummondii*. In addition to Texas, this plant occurs in Brazil and Paraguay, and is widely distributed in Argentina. Fryxell theorizes that the establishment of the plant in Texas probably resulted from dispersal from the Southern Hemisphere. The actual dispersal agent is not known but on the basis of circumstantial evidence, Fryxell suggests that birds may have been involved.

Parrott et al. (1969) studied feeding stimulant and attractant characteristics of several malvaceous plants and concluded that of those tested *C. drummondii* (then known as *C. sulphurea*) and *Thespesia populnea* (L.) Soland. possessed the most suitable qualities as alternate hosts for the boll weevil.

The study reported herein began in June 1971 and continued through December 1973. The field work was conducted mostly in the Coastal Bend region of Texas (as defined by Gould and Box 1965) with occasional examinations of plants farther south in Willacy and Cameron Counties. Some laboratory studies were carried out at College Station. The principal purpose of the study was to investigate the field biology and ecology of *Anthonomus grandis* on *Cienfuegosia drummondii*. Aspects of the study receiving special attention were seasonal incidence of weevil infestations, larval and adult feeding habits, preference of the weevil for oviposition sites on the plants, relationship of parasites and predators to the weevil, and the distribution and ecology of the plant in Texas.

DISTRIBUTION AND ECOLOGY OF *C. drummondii*

Distribution

As mentioned in the "Introduction," *C. drummondii* occurs in Argentina, Brazil, Paraguay, and South Texas. In Texas the plant is apparently confined mostly to the coastal counties extending from Calhoun County to Cameron County (fig. 1). The upper six of these counties (Calhoun, Refugio, Aransas, San Patricio, Nueces, and Kleberg) are sometimes referred to as the

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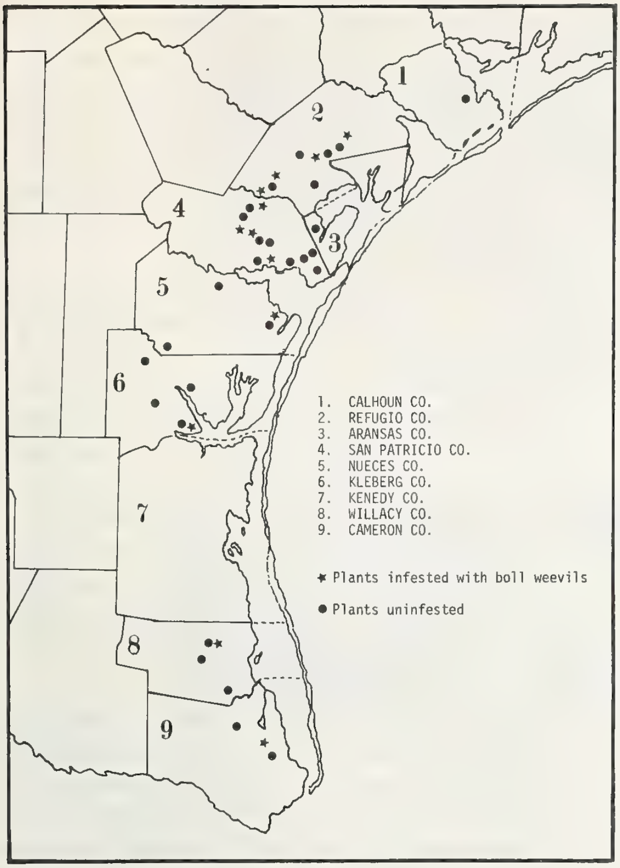


FIGURE 1.—Distribution of *Cienfuegosia drummondii* along the lower Texas gulf coast, with designation of localities infested by the boll weevil. Distribution based on records made during the present study, Fryxell (1969), and information provided by M. J. Lukefahr.

Coastal Bend region of Texas (Gould and Box 1965). Kenedy County is the only county in this series in which *C. drummondii* is not known to occur. The reason for this disjunction in an otherwise continuous distribution from north to south is probably due to the predominance of sandy soils in Kenedy County, which constitute an unfavorable habitat for the plant. The inaccessibility of most of the county resulting from the presence of large ranches and the lack of public roads has also discouraged search for the plant there. A narrow strip of land along the eastern edge of the county adjacent to the Laguna Madre apparently has clayey soils which may be suitable for colonization of the plant. In such case, a narrow corridor would be provided linking the northern and southern populations of the plant. Fryxel (1969) also cites two records of specimens collected from sites farther inland (at "Gonzales" and on the "banks of the Colorado above Austin"). These records were taken from herbarium specimens collected over 100 years ago and there is no evidence that the plant has been found to occur so far inland since. A 1925 record of the plant, "S of Dallas," is so vague as to be meaningless.

The northern limit of the distribution of *C. drummondii* in Texas coincides rather well with the line delimiting the northernmost extension of approximately 21° C or higher mean annual air temperatures and 22° C or higher soil temperatures (Godfrey et al. 1973). It is likely that temperature is the determining factor in distribution of the plant in the State. Some plants grown at College Station survived one mild winter in a somewhat protected place but were killed the following year by slightly lower temperatures.

Ecology

Soil and water requirements.—C. drummondii grows naturally only in clayey, poorly drained soils. Soils in South Texas in which the plant has been observed to grow include Banquete clay, Edroy clay, Orelia clay loam, Raymondville clay loam, and Victoria clay. According to Gould and Box (1965) the major portion of the Coastal Bend region is composed primarily of soils of the Victoria series. These are called blackland, and are sticky when wet, cracked when dry, and are poorly drained. These characteristics are apparently optimum for growth of *C. drummondii*, and therefore the plant could potentially thrive throughout most of the Coastal Bend area. It should also be pointed out that these soils are adaptable for cultivation of cotton so that it is to be expected that cotton and *Cienfuegosia* often grow in close proximity to each other. *Cienfuegosia* plants are often found growing along the edges of roadside ditches and shallow depressions which catch and hold water for varying periods of time. We have not observed plants growing around more or less permanent bodies of water. In addition to the habitats mentioned above, *Cienfuegosia* may occur along fencerows, under shrubby vegetation and in waste areas wherever drainage is poor.

Fryxell (1969) states that in Argentina this species occurs in heavy, often saline soils where the plants appear to demonstrate a high salt tolerance. In Texas, *Cienfuegosia* is frequently found growing in saline habitats but probably does not occur in highly saline habitats characterized by succulent plants.

Associated plants. — *Cienfuegosia* grows among the plants typically found in low, poorly drained areas; for example, *Eleocharis* and *Cyperus* spp. and various grasses. Other plants frequently encountered in these areas include *Lythrum lanceolatum* Ell., *Mecardonia vandellioides* (H.B.K.) Pennell, *Melochia pyramidata* L., *Oxalis drummondii* Gray, *Polygonum hydropiperoides* Michx., *Ruellia runyonii* Tharp and Barkley, *Rumex pulcher* L., *Sida ciliaris* L., *Solanum americanum* Mull., *Tradescantia micrantha* Torr., and *Zephyranthes refugiensis* F.S. Jones. *Cienfuegosia* does not exhibit a marked preference for either full sunlight or shade and is frequently found in both situations. It commonly occurs beneath mesquite and also in open areas between the various shrub species such as *Acacia, Berberis, Celtis, Forestiera* and *Zanthoxylum* (figs. 3 and 4). The plant frequently occurs in close proximity to cultivated cotton in these brushy areas.

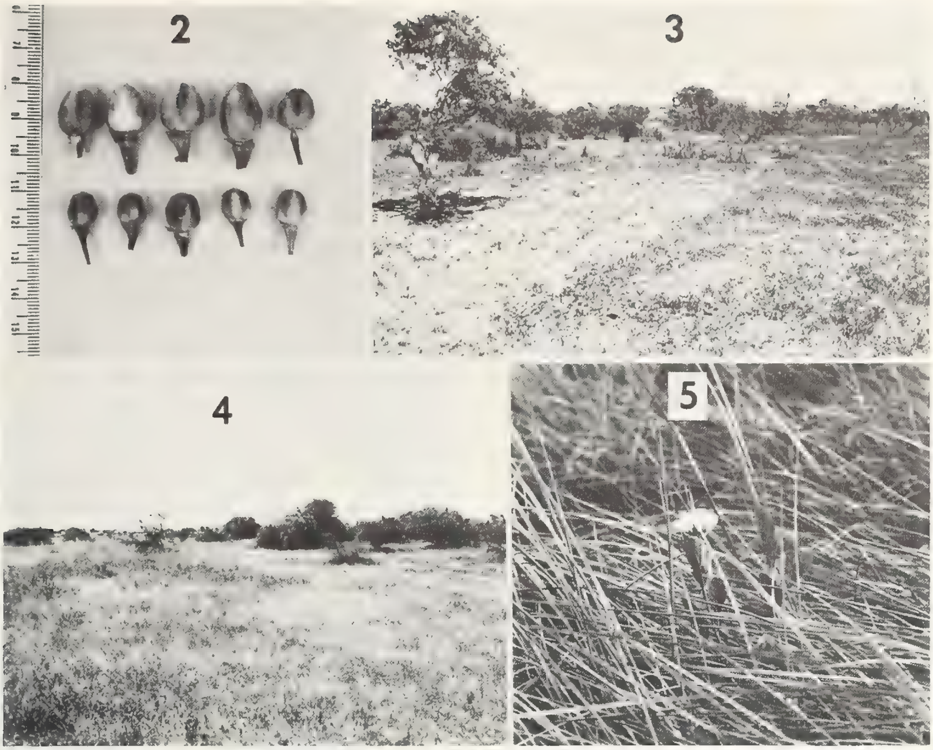
At Riviera Beach in Kleberg County an occasional plant is found in association with sea oxeye daisy, *Borrichia frutescens* (L.) D.C., on a low bluff just a few feet from the water of Baffin Bay. *Cienfuegosia* grows only sparingly in this particular habitat. Adjacent to the sea ox-eye community, *Cienfuegosia* grows among an almost pure stand of gulf cordgrass, *Spartina spartinae* (Trin.) Hitchc. (fig. 5). These plants growing in the cordgrass community are usually characterized by greatly elongated stems. A narrow, occasionally mowed strip through the cordgrass at this locality supports a dense stand of short-stemmed *Cienfuegosia*.

Associated insects.—In addition to the boll weevil, *C. drummondii* is fed upon by several other insects, most of which also attack cultivated cotton. Lukefahr and Martin (1962) mention that larvae of the cotton square borer, *Strymon melinus* (Hübner), and the barberpole caterpillar, *Noctuelia rufofascialis* (Stephens), were reared from the plant. During the present study these two species were at times found to be common on *Cienfuegosia* and frequently considerably damaged flowerbuds and seed capsules.

Lukefahr and Martin (1962, 1965) also mention the association of the cotton leafworm, *Alabama argillacea* (Hübner), with *C. drummondii.* On October 2, 1973, during the present study, an infestation of leafworms was observed on *Cienfuegosia* near Corpus Christi. The plants were heavily infested and the leafworm larvae stripped most of the foliage from the plants over a rather large area.

The boll weevil and the other species mentioned above are the only ones found which significantly damage *C. drummondii* in South Texas. An occasional saltmarsh caterpillar, *Estigmene acrea* (Drury), was observed feeding on the plants. In addition, several insects were found associated with the flowers of this plant. The chrysomelid beetle, *Diabrotica connexa* LeC., was one of the more abundant species feeding on the flowers. Other insects occurring in the flowers included *Epicauta* sp., tettigoniid nymphs, buprestids, and an occasional bee, cantharid and mirid.

Flowering and fruiting pattern.—Flowering of *C. drummondii* is erratic, and is apparently initiated for the most part by the occurrence of rains. Following rains, a brief period of profuse flowering generally occurs. As available moisture decreases, flowering within a population of *Cienfuegosia* either ceases altogether or its incidence drops to a low level. The latter appears to be the case in populations which were observed during the present study. The few plants of a given population existing in more favorable sites for water retention continue to flower and produce fruit while the majority of plants at the locality are vegetative. Observations on five populations of plants (see tables 1, 2, 3 for localities) over periods ranging from 2 to 3 years indicate that buds or seed capsules or both may be present at a particular locality during most of the growing season. It should be noted that the data on which the duration of fruiting is calculated in tables 1, 2, and 3 are based on the number of fruiting forms counted on 10 plants at each locality. These plants were chosen at random on each sampling date, so the phenology of individual plants was not followed through the season. The vertical lines denoting the fruiting periods in tables 1, 2, and 3 also do not indicate the abundance of buds or fruit, although these data were recorded during the study and are available. The object here was merely to indicate



Figures 2–5.—2, Comparison of fruit developing from chasmogamous and cleistogamous flowers. Top row, chasmogamous; bottom row, cleistogamous. 3, Heavily grazed pasture near Corpus Christi. Large population of *C. drummondii* in foreground along right side of photograph. Shrubby vegetation in background is mesquite, *Acacia*, *Forestiera*, and *Xanthoxylum*. 4, *C. drummondii* in vegetative state in grass, *Acacia*, and mesquite habitat near Refugio. 5, *C. drummondii* flowering above dense mat of gulf cordgrass at Riviera Beach.

at which times of the year some buds or fruit were available as a source of food for adult weevils and as sites for larval development.

March 29 was the earliest date on which fruit was observed at any locality during the 3-year study. At the Refugio locality (table 3) in 1973, buds or capsules or both were present continuously from May 7 through December 18, although at various times these were relatively scarce. At Riviera Beach during 1973 (table 3), the plants were first noted to be fruiting on April 23 and continued to fruit through October 3. On the following sampling date (October 14), no fruit was found at this last locality, but by October 24 the plants commenced fruiting again and continued to do so through December 18. This is the latest date on which *C. drummondii* was observed to fruit.

Fryxell (1963) was the first to draw attention to the production of cleistogamous flowers by *C. drummondii*. He stated that in the greenhouse and in the open, this plant produces both chasmogamous and cleistogamous flowers in approximately equal numbers. During the present study additional data were collected on cleistogamy, especially as it relates to infestations of *C. drummondii* by the boll weevil. Fruit developing from cleistogamous flowers on the average are smaller than those developing from chasmogamous flowers. The two types can easily be distinguished by the chasmogamous fruit's having a more acutely pointed apex (fig. 2).

A total of 4,247 capsules of *Cienfuegosia* were collected during this study from several localities, mostly in Refugio, San Patricio, Neuces, and Kleberg Counties. Of this number, 2,425 (57.1%) capsules were from cleistogamous flowers and 1,822 (42.9%) were from chasmogamous flowers (table 4). These figures should represent a fair approximation of the relative frequency of the two types of fruit in the field, since no conscious attempt was made to select either of the two. The two types were nearly always found together at the same locality; a sample was rarely composed entirely of one type. In fact, cleistogamous and chasmogamous

TABLE 1.—*Infestation of* Cienfuegosia drummondii *by* Anthonomus grandis *in South Texas, 1971*

Date	Percent infestation[1]		
	Sinton	Woodsboro, 8 mi south	Riviera Beach[2]
June 9	4.8	9.0	....
June 23	3.0	7.7	....
July 11	0	0	....
July 27	0	0	10.1
Aug. 11	12.5	0	32.0
Aug. 26	20.7	0	4.7
Sept. 27	0	0	10.3
Oct. 11	0	0	5.3
Nov. 2	0	0	17.2
Nov. 13	0	0	24.6
Nov. 30	0	...	8.2
Dec. 18	....	...	7.1

[1] Eggs, larvae, and pupae in capsules and flowerbuds combined. Vertical lines indicates period during which plants bore buds or capsules or both.

[2] First sample from locality taken on July 27.

fruit frequently occur on the same plant. Both types of fruit occur throughout the entire fruiting period of the plants, with no indication that either is more prevalent at any time during the season.

DEVELOPMENT OF THE BOLL WEEVIL ON *C. drummondii*

Methods.—Field studies on the association of the boll weevil with *C. drummondii* were conducted mostly in the Coastal Bend region of Texas. Occasional visits were made to *Cienfuegosia* localities in Willacy and Cameron Counties, but these were never established on a regular basis. In the Coastal Bend region an attempt was made to examine each of the selected localities at either weekly or biweekly intervals throughout the growing season. Localities sampled on a regular basis are listed in tables 1, 2, and 3.

Data collected in the field at each site included determination of the growing condition of the plant, the number of fruiting forms per 10 plants, and the associated plants and insects. Counts were also made to determine the number of adult weevils present. During each visit fruiting forms were collected to be examined later in the laboratory. These buds and capsules were examined by dissection, and records were made of the number of eggs, larvae, and pupae present; the larval instars represented; the incidence of parasitization; and larval feeding habits. An attempt was made to dissect at least 25 buds and 25 capsules from each locality every 2 weeks, but this number varied considerably depending upon the availability of fruiting forms.

Larvae of the boll weevil were reared in the laboratory in detached capsules by transferring them periodically to fresh fruit. In transferring a larva, a hole was bored in the fresh fruit with a large syringe needle, the larva was placed in the hole, and the outside opening was closed with molding clay. The clay plug served to delay dessication of the fruit and also prevented the larva from escaping. This method worked quite satisfactorily on a small scale for the purpose of observing feeding habits of the larvae, duration of larval stages, and for rearing parasites to the adult stage.

Distribution of infestations.—Reference to figure 1 shows that boll weevils have been found associated with *C. drummondii* only at about one-third of the localities where the plant is known to occur. However, it should be explained that at some of these localities only one or a few examinations of the plants were made. Furthermore, in some localities plant populations are small and may either not be infested or be so lightly infested as not to be easily detectable. More extensive inspection over a longer period of time would likely reveal at least light infestations at additional sites.

We were unable to correlate the presence or absence of weevils on *C. drummondii* with the distance of the plants from cultivated cotton. In some cases uninfested *Cienfuegosia* plants were actually located closer to cotton fields than were infested plants. In the Coastal Bend region it is impossible to find *C. drummondii* at any great distance from cotton. This is not ascribable to any faculatative association of the two plants, but merely to the fact that soil and moisture requirements of *C. drummondii* coincide with those considered best in the area for cotton cultivation. Some of the localities at which the boll weevil was found on *Cienfuegosia* were within a mile of cultivated cotton, while others were at least 8 miles from the nearest cottonfield. Lukefahr and Martin (1962) stated that they found weevils on *Cienfuegosia* on the Welder Wildlife Refuge approximately 10 miles from cottonfields.

TABLE 2.—*Infestation of* Cienfuegosia drummondii *by* Anthonomus grandis *in South Texas, 1972*

Date	Percent infestation[1]				
	Riviera Beach	Sinton	Woodsboro, 8 mi South	Refugio[2]	Corpus Christi[3]
Mar. 14	0	0	0	....	....
Mar. 29	16.7	0	0	....	....
Apr. 11	17.6	0	0	....	....
Apr. 26	0	0	0	....	....
May 10	4.7	0	0	....	....
May 24	8.3	0	0	....	....
June 14	2.9	16.4	6.0	....	....
June 21	5.6	11.7	....	....	....
June 29	....	....	5.2	8.0	....
July 6	0	0	0	6.4	....
July 20	0	0	0	0	....
July 28	0	6.6	25.0	9.1	....
Aug. 9	15.5	3.4	18.9	2.0	13.3
Aug. 23	0	0	11.1	21.0	10.3
Sept. 6	0	....	0	0	0
Sept. 20	0	0	0	0	0
Oct. 4	0	0	0	0	0
Oct. 18	0	0	0	0	40.9

[1] Eggs, larvae, and pupae in capsules and flowerbuds combined. Vertical lines indicate period during which plants bore buds or capsules or both.

[2] First sample from locality taken on June 29.

[3] First sample from locality taken on Aug. 9. Plants continued to fruit through Dec. 13.

TABLE 3.—*Infestation of* Cienfuegosia drummondii *by* Anthonomus grandis *in South Texas, 1973*

Date	Percent infestation[1]				
	Riviera Beach	Sinton	Woodsboro, 8 mi south	Refugio	Corpus Christi
Mar. 26	0	0	0	0	0
Apr. 9	0	0	0	0	0
Apr. 23	0	0	0	0	0
May 7	0	0	0	0	0
May 21	0	0	3.4	0	2.3
June 6	0	0	0	0	0
June 18	0	7.4	0	0	0
July 3	0	28.1	0	0	1.8
July 20	0	0	1.7	6.1	10.5
Aug. 1	0	0	0	8.0	8.0
Aug. 14	10.5	0	10.0	11.3	6.6
Aug. 21	28.0	0	22.8	38.0	13.5
Aug. 28	27.2	0	22.2	40.0	16.0
Sept. 4	6.9	0	34.7	38.5	22.7
Sept. 11	....	0	23.2	40.0	26.6
Sept. 18	0	0	32.1	46.0	7.1
Sept. 25	0	0	0	38.0	0
Oct. 3	8.3	0	0	23.7	0
Oct. 14	0	0	0	18.0	0
Oct. 24	9.1	0	0	4.0	0
Nov. 6	10.7	0	0	0	0
Dec. 18	0	0	0	0	0

[1] Eggs, larvae, and pupae in capsules and flowerbuds combined. Vertical lines indicate period during which plants bore buds or capsules or both.

TABLE 4.—*Incidence of infestation of flowerbuds and seed capsules of* C. drummondii *by* A. grandis

Plant part	No. examined	Percent capsules	Percent infested[1]
Buds	900	.....	18.3
Capsules (4,247):			
Cleistogamous	2,425	57.1	8.0
Chasmogamous	1,822	42.9	5.7
Total	5,147	100.0	[2]13.7

[1] Rate of infestation based on eggs, larvae, and pupae.
[2] Total capsules only.

Seasonal incidence of infestations.—No regular seasonal pattern involving the infestation of *C. drummondii* by the boll weevil is evident from the data gathered during the 3 years of this study (tables 1, 2, and 3). At the Sinton locality, infestations were always erratic and of short duration. On the other hand, one infestation at Riviera Beach in 1971 extended continuously over a period of 145 days and the first sample from this site was not taken until July 27, after the season was well advanced. In 1972 at this locality, the plants were continuously infested for 85 days, while in 1973 there were two periods of infestation, one lasting 22 days and the other 34 days. It is of interest that at Riviera Beach in 1972 the earliest infestation was on March 29, whereas in 1973 the first signs of weevil infestation did not occur at this locality until August 14. At Refugio, the longest observed period of continuous infestation was 94 days in 1973. At Corpus Christi in 1973, an infestation lasted 77 days.

Using 25 days as an approximate average duration of a complete generation, it is possible for as many as five or six generations to have developed at Riviera Beach in 1971 on *C. drummondii.* Two or three generations could have developed at some of the other sites mentioned above.

At the five localities studied, weevil infestations usually occurred any time buds or seed capsules were available on which to feed and develop, though there were some notable exceptions to this (tables 1, 2, and 3). For example, at Riviera Beach in 1973, fruiting forms were present for 114 days before weevil infestations were detected. In some other cases a generation of weevils developed on the plants but did not reinfest them, although buds or capsules continued to be available for a fairly long period of time. Fruiting forms were also available at some other localities, such as Sinton and 8 miles south of Woodsboro in 1971 (table 1), long after weevil infestations were no longer detected.

Infestations based on the number of immature forms present in flowerbuds and seed capsules as determined by dissection were usually considerably less than 30% (tables 1, 2, and 3). The heaviest infestation recorded during the 3-year study occurred at the Refugio locality in 1973 (table 3). At this site, weekly infestations varied from 38% to 46% during the period August 21 through September 25.

It was not possible in the present study to determine the full extent of interaction between cotton and *Cienfuegosia* in maintaining populations of weevils. Obviously, some movement of weevils does occur between the two plants, at least in certain areas. For example, on August 19, cotton in the area of Riviera Beach had matured to the point where it no longer provided food for weevils, and at that time there was a significant increase of adult weevils on *Cienfuegosia* less than 2 miles from the nearest weevil-infested cottonfield. Since many of the weevils on cotton at that time had developed in bolls, they were larger than weevils developing on *Cienfuegosia* and hence were recognizable as having transferred from cotton. It should be noted that at this locality weevil infestations on *Cienfuegosia* continued until December 18, approximately 122 days after cotton ceased to provide feeding and developmental sites in the area (table 1). In this case the period of availability of food for weevils was considerably extended by *Cienfuegosia.* The same situation was found to exist in other localities.

In the Coastal Bend region, cotton squares are usually first available as sites for weevil feeding and development sometime during the latter half of May. It may be noted in tables 2 and 3 that infestations of weevils also begin on *Cienfuegosia* at about this time, although flowerbuds and seed capsules are available earlier. The earliest infestation on *Cienfuegosia* recorded during the entire study was March 29 at Riviera Beach, thus preceding the first available cotton squares by approximately 1½ months; however, it appears on the basis of data presented here that initial infestations on *Cienfuegosia* generally coincide rather well with the first availability of squares on cotton.

Longevity of adult weevils on Cienfuegosia.—Studies were conducted in the laboratory at College Station to determine the longevity of weevils fed exclusively on the seed capsules of *C. drummondii.* These fragmentary results were undoubtedly affected by the inconsistent supply of suitable food at certain times, but the conclusion drawn is that weevils may survive for fairly long periods on *Cienfuegosia* fruit alone. Twenty-two apparently healthy adults reared from *Cienfuegosia* from the Coastal Bend region and fed on seed capsules in the laboratory lived from 6 to 183 days (av. 69.6). In some cases the weevils obviously died from the lack of a plentiful quantity of suitable food, especially late in the season. In fact, the longest lived specimen (183 days) was still alive when the experiment was terminated because of a lack of fresh capsules.

The maximum period of longevity of 183 days reported here exceeds those which Szumkowski (1952) determined for the boll weevil on *Cienfuegosia affinis* (H.B.K.) Hochr. (177 days) and cultivated cotton (155 days) in Venezuela. No attempt was made to determine the longevity of the weevil on flowerbuds of *C. drummondii,* but it should be noted that buds would probably provide a more generally suitable food than do seed capsules. Weevils feed very readily on the younger, more tender seed capsules but sparingly, or not at all, on th older, harder capsules. It may also be mentioned that adult weevils will feed to a limited extent on the tender foliage of *C. drummondii.* Although this is not likely a major source of food under natural conditions, tender foliage may provide sufficient food for survival when buds and capsules are not available.

Ovipositional habits of weevils.—A total of 5,147 flowerbuds and seed capsules were dissected during the present study to determine preferences of adult weevils for ovipositional sites, and also to learn something of larval feeding habits. Of the 900 flowerbuds examined, 18.3% were infested with immature stages of the weevil (table 4). In comparison, 13.7% of 4,247 seed capsules examined were infested. These data indicate a preference of the weevil for oviposition in flowerbuds as compared with fruit. Furthermore, the fruit collected were subdivided into those developing from chasmogamous flowers and those developing from cleistogamous flowers in an attempt to determine if weevils showed a preference for one over the other as an ovipositional site. The infestation of cleistogamous fruit was 8% as compared with 5.7% for fruit developing from chasmogamous flowers. Controlled experiments will be necessary to determine the significance of this difference. As a possible explanation of the indicated difference for the two types of fruit, we have noticed that the walls of fruit developed from cleistogamous flowers appear to be somewhat softer than those of chasmogamous fruit, especially as the capsules approach maturity. This may account for the higher percentage of egg deposition in the cleistogamous fruit.

Our observations indicate that eggs are deposited through the wall of the capsule about one-half the distance between the apex and base of the fruit, and are usually inserted directly into a seed.

Larval and pupal habits.—Newly emerged larvae feed on the outside of a seed within the capsule, often burrowing along the outer surface of the seedcoat. The larva then enters the seed and devours its contents, after which it chews into an adjacent seed and continues feeding. Larvae usually complete their development without devouring the entire contents of a capsule. After completing larval development, a cell is formed in the feeding cavity in which pupation takes place. Buds and capsules remain attached to the plants during larval development and pupation.

Normally only one larva is found in a bud or capsule. Occasionally two larvae occur in the same capsule, but we have seen no evidence to indicate that both are able to complete their development there. In one instance three larvae, two second instar and one third instar, were found in the same capsule.

The boll weevil on *C. drummondii* has three larval instars. Head capsule measurements are as follows: first instar, 0.38–0.42 mm, av. 0.40 mm; second instar, 0.65–0.77 mm, av. 0.71 mm; third instar, 0.81–1.26 mm, av. 1.05 mm. These compare favorably in size with mean head capsule measurements of laboratory-reared boll weevil larvae reported by Parrott et al. (1970).

Incidence of parasitization.—A total of 500 larvae of *A. grandis* were dissected from buds and capsules of *C. drummondii* in the Coastal Bend region. Only 6 larvae of the 500 examined were parasitized, 5 of these being collected in 1972. Four braconid wasps were reared. One is tentatively determined here as *Bracon mellitor* Say, one specimen was identified as *Bracon* sp. (the latter determined by P. M. Marsh, Agricultural Research Service, U.S. Department of Agriculture), and the remaining two specimens are obviously also members of the genus *Bracon*.

SUMMARY AND DISCUSSION

The study reported herein was conducted to provide information on the relationship of *Anthonomus grandis* with *Cienfuegosia drummondii*, a wild host plant of the weevil in South Texas. Since relatively little was known about the weevil on this host, rather broad objectives were set forth so as to touch upon as many aspects of the relationship as possible. It was anticipated that this primarily field-oriented study would bring to light certain areas in the relationship worthy of subsequent concentrated study. Because of the exploratory nature of our work on this subject, the present report is of necessity mostly descriptive.

Cienfuegosia drummondii is apparently a South American plant which became established in Texas and is now known to occur in all coastal counties (except Kenedy County) from Calhoun County south to Cameron County. Within this area the plant occurs in clayey soils which are poorly drained. It is associated with a wide variety of plants which normally occur in poorly drained areas within its range in Texas. The plant sometimes occurs in rather large populations, especially in the northern part of its range, in the vicinity of Corpus Christi, where it is also considerably more abundant than further south. If the plant is indeed an introduced one, then it appears that this introduction originally took place in the Corpus Christi area since that is the center of distribution of the plant in Texas at the present time. In the larger populations of plants, buds or fruit are usually available over a large portion of the growing season, although the quantity of fruit available varies considerably.

It is of interest to note that in addition to the boll weevil, *C. drummondii* serves as host for other cotton pests, namely the cotton square borer and the cotton leafworm. These, plus the barberpole caterpillar and an occasional saltmarsh caterpillar, constitute the major phytophagous insects associated with *Cienfuegosia* in Texas.

Plants at only approximately one-third of the localities known for *Cienfuegosia* have been found to be infested with boll weevils but additional examinations will likely increase the known infestation percentage. Most of the localities now known to be infested are in Refugio and San Patricio Counties. During this study, plants in five localities in the Coastal Bend region of Texas were examined for weevil infestations weekly or biweekly for nearly 3 years. Plants at each of these localities were infested with weevils for varying lengths of time during the study period. The longest continuous infestation noted was 145 days at Riviera Beach in 1971.

Infestation counts on field-collected buds and seed capsules indicated that females show a preference for flowerbuds as ovipositional sites, although by virtue of their being more abundant most of the time and being available for a longer period of time, seed capsules produce the largest number of weevils.

Observations were made on larval feeding habits and these habits were not found to differ essentially from those described for cultivated cotton. Larvae were found to have three instars.

The parasitization rate of weevil larvae based on dissection of buds and seed capsules was found to be low. Only 6 parasites were observed attacking the 500 weevil larvae examined. All of the parasitoids reared are members of the hymenopterous genus *Bracon*.

On the basis of information gained during this study, we are of the opinion that the boll weevil would be able to maintain at least small populations on *Cienfuegosia drummondii* in South Texas in the absence of cultivated cotton. The weevil readily develops on *Cienfuegosia* in natural situations, sometimes several miles distant from cotton. In some of the localities examined there is no evidence that any regular exchange of weevils takes place between *Cienfuegosia* and cotton, whereas in other areas there is obviously some exchange between the two plants. Furthermore, buds or seed capsules are available in the larger populations of plants for most of the growing season, thus providing a continuous supply of food and developmental sites for the weevils. A further indication of the adaptation of the boll weevil to *Cienfuegosia* is the widespread weevil infestation on the plant along the lower gulf coast of Texas. Although the infestations are scattered, they occur essentially throughout the range of the plant in Texas. It is also significant that the ovipositional habits of the female weevil and the feeding habits of the larvae are not unlike those noted for the species on cultivated cotton. Larvae develop normally in flowerbuds and capsules of the plant, and adults are able to live for long periods of time with capsules as the only source of food. Specimens reared on *Cienfuegosia* are also comparable in size to those reared on squares of cultivated cotton and on artificial media in the laboratory.

Because of the scattered nature of the plant, its somewhat erratic fruiting pattern, and the often small number of buds and seed capsules available as developmental sites, it is obvious that large numbers of weevils are not likely to be maintained on *Cienfuegosia*. We feel that the importance of *C. drummondii* as an alternate host of the boll weevil in South Texas lies in its ability to support small populations of weevils which could form the nucleus of infestations of cultivated cotton.

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BIOLOGICAL CONTROL AGENTS OF THE BOLL WEEVIL

By D. G. Bottrell[1]

R. L. Doutt (1967), one of the world's most respected authorities in biological control, aptly describes the outstanding advantages of using biotic agents for control of pest species:

"Biological control of invertebrate pests and weeds has enormous and unique advantages. This splendid control measure, which is a tribute to man's knowledge of the functioning biotic world about him, is now officially designated as the preferred method of insect suppression by the Entomological Society of America (ESA), the organization to which all leading professional entomologists of the United States and Canada belong. (Statement on Pesticides. March 1964. Bull. Entomol. Soc. Amer. 10: 18.)

"Biological control is especially desirable because it is *safe, permanent,* and *economical.* It is thus unique, for no other control measure has this wonderful combination of advantages, and on logical grounds it has been strongly advocated as the first line of attack in pest suppression. Furthermore, biological control is remarkably durable. It has lasted through years of neglect by the entomological profession and through years of appalling ignorance. It has endured criticism and has survived direct attacks by articulate, powerful, and self-serving antagonists. Finally, it has abided while one by one various pest control fads and numerous commercial products, all proposed as panaceas, have failed and faded into oblivion."

Unfortunately, the great majority of boll weevil researchers and their administrators alike are too nearsighted to share Doutt's views. For, in spite of the fact that ESA has designated biological control as the preferred method of insect suppression, support (both financial and moral) for work on natural enemies of boll weevil currently rests at the foot of the low priorities. As table 1 shows, research emphasis on biological control of this pest in fiscal 1972 at the U.S. Department of Agriculture (USDA) and land-grant university laboratories amounted to a total of 2.6 scientific man-years (SMY's) and $90,000 support—this compared to 5.0 SMY's and $395,000 support for chemical control research and 7.8 SMY's and $736,000 support for research on rearing, sterility, and genetics. Although support on biological control of boll weevil is being grossly underemphasized, support for such work on the pink bollworm, *Pectinophora gossypiella* (Saunders), and the bollworm-tobacco budworm complex appears to be fairly reasonable (table 2).

Through sheer ignorance, most cotton entomologists slough off the role of natural enemies in the control of boll weevil. Some, in fact, believe that the pest has no natural enemies, or at least their writings seem to indicate this.

The fact remains that the boll weevil does have numerous natural enemies, and some of them are extremely important in suppressing the pest's population. Sixty-two years ago, Pierce (1912) summarized information known about predatory and parasitic enemies of the pest as follows: (1) "The control of the boll weevil by insect enemies is sufficiently great to give it a high rank in the struggle against the pest. A considerable portion of the insect control would not be accomplished by any other factor; hence it is by no means to be neglected." (2) "The amount of control due to the various factors at work in any given place should be increased if possible. Parasites can be introduced into new fields." (3) "The parasites and preda-

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TABLE 1.—*Relative inputs of scientific man-years (SMY's) and dollars into several areas of boll weevil research at all USDA and land-grant university laboratories, 1972*[1]

Area of research	SMY's	1,000 dollars
Biological control	2.6	90
Chemical control	5.0	395
Cultural control	1.8	99
Population dynamics	.7	27
Basic physiology, nutrition., biology, etc.	3.9	422
Rearing, sterility, genetics	7.8	736
Economic threshold, economic evaluations	3.8	454
Integrated pest management	8.2	667

[1] Estimates compiled by G. A. Slater, based on 1972 fiscal Current Research Information System printouts of RPA 207, cotton research.

TABLE 2.—*Inputs of scientific man-years (SMY's) and dollars into biological control research on various cotton insect pests at all USDA and land-grant university laboratories, 1972*[1]

Insect	SMY's	1,000 dollars
Boll weevil	2.6	90
Pink bollworm	4.0	326
Bollworm and tobacco budworm complex	6.5	415

[1] Estimates compiled by G. A. Slater, based on 1972 fiscal Current Research Information System printouts of RPA 207, cotton research.

tors which attack the boll weevil are native insects, already present in a given territory before the weevil arrives."

In addition to predatory and parasitic insects, numerous species of spiders are known to attack boll weevil. Birds, under certain conditions, attack the pest and probably assist in keeping it in check. Howell (1907), for example, reported 43 species of birds feeding on the boll weevil and proposed (1907, 1909) that legislation be enacted to protect species known to prey on the pest. Even cryptic predators such as toads and lizards sometimes attack boll weevils. Roach (1973) recently reported an average of 0.5 boll weevil per stomach of Fowler's toad examined in southern Mississippi. However, it is doubtful if vertebrate predators and, to a lesser extent, arthropod predators play a highly significant role in controlling the weevil under most cotton growing situations.

More is known about the boll weevil's insect and mite parasites than about its other natural enemies. Forty-two species of arthropod parasites have been recorded by Cross and Chestnut (1971) as attackers of the pest. Among the more effective native species of parasites are *Bracon mellitor* Say in the United States (Adams et al. 1969), and *Heterolaccus grandis* Burks in western Mexico and Central America (Cross and Mitchell 1969).

B. mellitor is an ectoparasite of latter instar boll weevil larvae and pupae. This general parasite attacks a wide range of hosts, but surprisingly enough is often fairly effective in suppressing boll weevil populations. Recent studies in untreated cotton fields in Texas have revealed that parasitization by *B. mellitor* is related to the host (boll weevil) density (table 3). As shown under the *dfx* columns of the life tables, i.e., the columns which list factors responsible for percentage mortality (100*qx*) recorded for the life stages, the level of parasitization is greater in the field with the higher population density. A tendency toward a functional density-dependent relationship, although this relationship appears to be weak, was also disclosed when the parasitization rate was determined for various densities of immature boll weevils inhabitating fallen cotton squares (fig. 1).

Few pathogens have been observed to attack the boll weevil under natural conditions (Cross 1973), but recent observations suggest that certain pathogens might have tremendous potential as control tools if they could be augmented safely and economically. The protozoans *Glugea gasti* and *Mattesia grandis* have shown great promise when distributed over cotton in baits which the boll weevils fed upon (McLaughlin et al. 1969). Their application precluded the need for insecticide to control boll weevil in a field test in Mississippi. Furthermore, D. S. Moody and S. Munoz (unpublished data) recently found some interesting information concerning the treatment of laboratory-reared adult boll weevils with *Aspergillus flavus*, a common fungus. One strain was highly sex selective, causing 88.7% mortality in females, as contrasted to only 22.8% mortality in males.

TABLE 3.—*Partial life tables for first summer generation of boll weevils of two population densities in untreated cotton, Schleicher County, Tex., 1972*

Life stage X	Population density lx (No./acre)	Percent mortality $100qx$	Mortality factors dfx
46% infested squares:			
Eggs	30,800	4.0	?
Small larvae	29,568	1.8	?
Medium larvae	29,036	12.2	?
Large larvae	25,494	9.6	Parasitization = 50%; ? = 50%.
Pupae	23,047	99.1	Parasitization = 42.1%; ? = 57.9%.
Adults	200	...	...
15% infested squares:			
Eggs	15,200	.5	?
Small larvae	15,124	2.1	?
Medium larvae	14,806	4.2	?
Large larvae	13,305	6.2	Parasitization = 6.7%; ? = 93.3%.
Pupae	12,481	84.8	Parasitization = 5.6%; ? = 94.4%.
Adults	1,900	...	...

The whole field of biological control of the boll weevil needs to be reexamined and, more importantly, fortified with imagination and administrative support. Some highly imaginative, classical studies were conducted on biological control of the boll weevil during the first 15 years or so after the pest entered the United States. In fact, probably some of the best entomological research, especially in insect ecology, conducted in North America during the early 1900's was on biological control of boll weevil.

However, as the publication listing by dates in table 4 indicates, emphasis on biological control and imaginative research in this area began to dwindle in the early 1920's, or about the time calcium arsenate first came into use. Although some work was continued in biological control during the 1930's, 1940's, and 1950's, it was done on very small, unimaginative scale when compared to the work during the "early" weevil years. In the past decade, nearly all work on biological control has been centered in one U.S. laboratory (the Boll Weevil Research Laboratory, Agricultural Research Service, Mississippi State, Miss.), although the U.S./Integrated Pest Management project has recently allowed initiation of some of this work in Texas.

Areas in biological control needing special

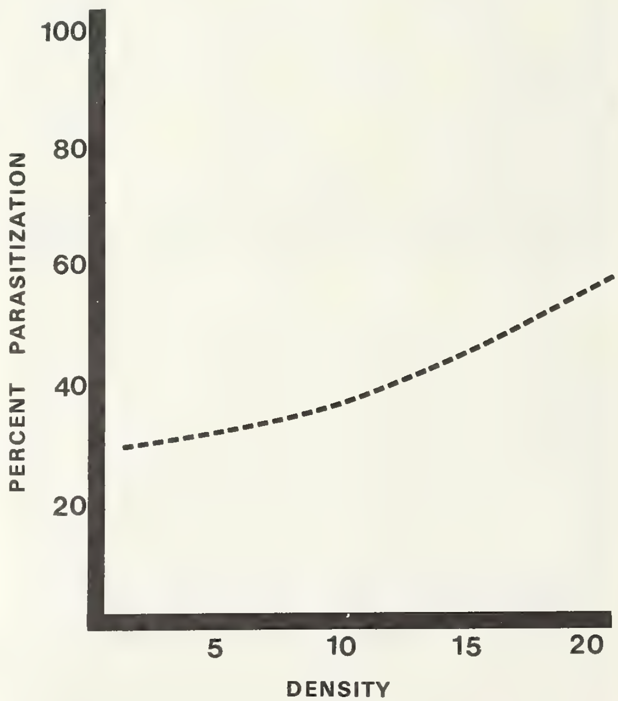

FIGURE 1.—Response of parasite to population density of its host, the boll weevil. Density = number of weevil-infested squares per 25 feet of cotton. Parasitization = percent squares yielding adults of primary native parasites.

TABLE 4.—*Numbers of publications concerned with various aspects on the biological control of boll weevil, 1843–1960*[1]

Period	No. publications	Percent of total
Prior to 1900	0	0
1900–10	37	53
1911–20	10	14
1921–30	4	6
1931–40	8	11
1941–50	5	7
1951–60	6	9
Total: 1843–1960	70	...

[1] Data compiled from Dunn, H. A. 1964. Cotton boll weevil, *anthonomus grandis* Boh.: Abstracts of research publications, 1843–1960. U.S. Dep. Agric. Misc. Publ. No. 985, 194 pp.

emphasis include (1) studies of the native parasites, pathogens, and predators which attack the boll weevil; studies of interspecies relationships; response to boll weevil density and to other hosts; role of hyperparasites; (2) manipulation strategies with native parasites (interplantings of cotton and wild plants that support alternate insect hosts of boll weevil parasites, etc.); use of "selective" baits impregnated with pathogens; and (3) discovery and importation of new natural enemies. Although there have been several attempts to introduce natural enemies for establishing controls on the boll weevil, work in foreign exploration and introduction has been especially neglected. Many opportunities are being passed over because this work is not being pursued.

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IN-SEASON CONTROL OF THE BOLL WEEVIL

By John S. Roussel[1]

The concept of "In-Season Control of the Boll Weevil" will not differ essentially from effective boll weevil control practiced in a sound cotton production program. Available technologies must be utilized to maximize effective control. Regardless of their location within the Cotton Belt, programs need to be designed to maintain boll weevil population levels at or below the economic threshold levels.

The importance of maintaining population levels at or below economic threshold levels was amply demonstrated in the initial year of the Pilot Boll Weevil Eradication Experiment. Population levels reached the saturation point prior to and at the time of beginning the diapause application, which resulted in a relatively inefficient diapause program. Large numbers of the boll weevil entered hibernation quarters and survived to emerge the following spring.

Studies on the biology of the boll weevil have demonstrated that the insect will enter the diapause condition quite early in the growth cycle of the cotton plant. Weevils have been collected as early as August 1 apparently in diapause in maturing fields. Phillips[2] believes that a small percentage of first generation field-reared weevils may be in diapause. There is no information concerning the role that weevils entering diapause at such an early date play in the final overall population of the current season and the succeeding season, but it is reasonable to assume that such a population must be controlled by one of the technologies employed, or failure will result.

The major objective of an in-season program is to retain the boll weevil population at a manageable level until the diapause control program is undertaken. The primary concern to the cotton producer, of course, is to set and mature a maximum crop. A secondary objective is to set and mature the crop so that growth will be terminated, the crop harvested, and stalk destroyed at the earliest possible date.

Technologies available to cotton producers for in-season control of the boll weevil are proved ones with which he is familiar, although he may not have used all of them in the past. These technologies include, in order of their use during the growth cycle of the cotton plant, trap crops and chemical controls. The use of trap crops is an important tool available to more efficiently control in-season boll weevil populations, but I wish to discuss chemical control in greater detail because it is commonly practiced by nearly all cotton producers in the boll weevil infested belt. Cotton producers are familiar with the requirements and the need for an efficient program. Some of the essentials of these control techniques include adequate monitoring of individual cottonfields by properly trained scouts, treatment of localized infestations that may develop in so-called hot spots or areas near favorable overwintering quarters, and uniform blanket treatment of the fields once the economic threshold level is reached in individual fields. Economic threshold levels established will vary between locations in the Cotton Belt, but under any circumstance, effective weevil control will have to be obtained and maintained throughout the growing season.

Applications of insecticides will of necessity have to be uniform and thorough with swath width limited to the capabilities of the specific equipment, but certainly no greater than that proved effective in past operations. Repeated applications of the insecticide at the proper interval for the specific chemical chosen will be essential in this phase of the program; e.g., ap-

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plication intervals should be no greater than 5 days for insecticides such as methyl parathion or Guthion.

During the course of a normal boll weevil control program, bollworms very often appear in damaging populations, and thus require control. Close monitoring and the inclusion of proper insecticide as a mixture with the regular program is essential to eliminate loss caused by this pest.

An important technique not currently available, but which could be of great significance in an eradication program, is the chemical termination of fruiting. Preliminary results in the western cotton area indicate this approach to have potential value in reducing the pink bollworm overwintering population. I see no reason why this approach should not be thoroughly researched as a possible tool in the boll weevil areas.

In-season control of the boll weevil is an essential element in any program of boll weevil control and elimination. To be successful, it will have to be performed in a thorough manner, with every producer and every field included. We already have the knowledge and methodology to suppress the weevil to an extremely low population level in preparation for a diapause program. Because a united effort is so important, leadership of the cotton industry must produce incentives which will assure the effective participation of every cotton producer in the Cotton Belt. Lack of cooperation on the part of any single producer will be critical in the ultimate success of the program.

REPRODUCTION-DIAPAUSE BOLL WEEVIL CONTROL

By Don R. Rummel[1]

The term "diapause control" has been generally accepted to describe a control method in which insecticide is applied to cotton late in the production season to destroy potential overwintering boll weevils before they enter overwintering habitat (Brazzel et al. 1959). Unfortunately, this term, which indicates the control of a physiological condition, is not technically correct. Diapause, which is induced in the immature stages and expressed in the adult stage, is not controlled by the application of insecticide. More appropriate terms which have been suggested include, "control of diapausing boll weevils," "control of potential overwintering weevils," and "control of prehibernating weevils.'

Reproduction-diapause control, originally outlined by Knipling,[2] describes a modification of the original concept of controlling prehibernating boll weevils, and consists of two separate phases. Phase I, or the reproduction-control phase, consists of a series of insecticide treatments applied to destroy the last generation of predominately reproductive weevils, thereby preventing the deposition of eggs which would produce a high percentage of diapausing individuals. The effectiveness of the reproduction-diapause control method was first demonstrated by Adkisson et al. (1965) and Lloyd et al. (1966).

Experience gained during the past 15 years has adequately demonstrated that both of these control techniques when applied properly are extremely effective methods of controlling boll weevils in some areas.

In the Texas High Plains a modified, reproduction-diapause control program has achieved reductions in the potential overwintering weevil population of up to 99% (Adkisson et al. 1966). In Glasscock County, Tex., a producer-sponsored program on 15,000 acres, utilizing three applications of insecticide, reduced the cost of in-season insect control 98.4% after only 2 years.[3] The tremendous reduction of the weevil population in the boll weevil eradication test zone can be attributed primarily to the effects of a "true" reproduction-diapause control program.

However, this control method is often oversimplified. A truly effective program must be based upon a sound knowledge of the ecology of the pest, and involves more than the random application of insecticide during the fall of the year.

Our experience in Texas has shown that diapause control programs with limited producer participation and improperly scheduled insecticide applications have invariably failed. In the High Plains suppression program, reduced finances have forced us to adopt a more limited control program during the past few years. With a decrease in both the number of insecticide applications and the amount of acreage treated, we have observed a marked decrease in percent suppression. Without question, one of the most important requirements for a successful suppression program is the treatment of all infested acres within the suppression zone. Ninety percent control on 100% of the infested area will

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[2] E. F. Knipling. An appraisal of the relative merits of insecticidal control directed against reproducing versus diapausing boll weevils in efforts to develop eradication procedures. A letter dated January 28, 1963, addressed to members of the Cotton Insects Research Branch, Entomology Research Division, Agricultural Research Service.

[3] Texas Agricultural Extension Service. Impact of diapause boll weevil control program on cotton insect control costs in Glasscock County, Texas. Memo. 1 p.

produce far superior results than 100% control on 90% of the area.

We are becoming more aware of real differences between populations in different ecological areas of Texas. Differences in the intensity of diapause, response to pheromone, winter survival, and migration have been noted. Therefore, it is necessary to base control efforts for a given region upon research conducted in that region.

In Frio County (South Texas), a reproduction-diapause control effort based upon the best obtainable data from other programs was conducted on a relatively small isolated acreage.[4] All sampling techniques indicated a high degree of suppression of potential overwintering boll weevils. However, by late June and early July of the following growing season, damaging weevil infestations were present in most fields, negating the effects of the fall suppression program. Weevil migration from untreated areas 15 to 20 miles away (a phenomenon we have not encountered in the High Plains and Rolling Plains) is considered as one possible reason for the failure of the program. Others have hypothesized that an extremely high rate of population increase may be responsible for the rapid resurgence of weevils during the summer. Based on this experience, there is some question as to whether current reproduction-diapause techniques can be applied effectively in all areas of the Cotton Belt.

Some factors which must be considered when implementing a suppression program are (1) the population dynamics of the weevil in a particular area, (2) the seasonal incidence of diapause and reproduction, (3) distribution and abundance of favorable overwintering habitat in relation to cotton, (4) the mean or expected degree of winter mortality, and (5) the influence of migratory weevils from untreated areas.

The control of potential overwintering weevils during late season offers numerous advantages to the cotton producer, including (1) more effective control, (2) greatly reduced costs as a result of elimination of or significant reduction in requirements for in-season insecticide application, (3) reduced probability of *Heliothis* and other secondary pest outbreaks as a result of reducing insecticide use during the growing season, and (4) less impact on beneficial arthropod populations (studies in High Plains area have shown that the fall suppression program had no deleterious effect on beneficial arthropod populations the following growing season). Without question, the control of potential overwintering weevils late in the growing season represents a vast improvement in insecticidal control of the boll weevil.

However, one potentially dangerous aspect of the reproduction-diapause control method must not be overlooked, and that is the danger of selecting populations resistant to the organophosphorus insecticides. The danger will increase if this method of control is adopted over large areas of the Cotton Belt. Heavy insecticide pressure exerted on potential overwintering populations over a large area will certainly increase the probability of the occurrence of organophosphorus resistance. There is some question as to whether the danger of resistance would be greater in large-scale pest management type programs or in a beltwide eradication effort. In my opinion, the massive application of the reproduction-diapause control technique in a beltwide eradication effort would present the greatest danger of resistance. Under a pest-management approach, even on a beltwide basis, many areas with subeconomic infestations could remain untreated, or require only limited treatment. The High Plains boll weevil suppression zone is bordered by areas in which limited amounts of insecticide are applied for weevil control. However, within the suppression zone, very heavy insecticidal pressure has been exerted on the weevil population for 10 consecutive years. To date no evidence of resistance to malathion has been detected in the weevil population within the suppression zone (table 1).

It is a mistake to consider reproduction-diapause control only as a major component of an eradication program. In areas where successfully tested, this control method can be considered a true pest management technique. A combination of reproduction-diapause or diapause control with certain cultural practices, such as delayed uniform planting dates, application of harvest-aid chemicals, and early harvest and stalk destruction, will produce a highly effective and economical pest-management system for many areas. There is considerable promise for developing effective boll weevil management

[4] Texas Agricultural Extension Service. Frio County Pest Management Program. 1972. Memo. 24 pp.

TABLE 1.—*Forty-eight-hour LD_{50} and LD_{90} values for boll weevils treated topically with malathion*[1]

[Micrograms insecticide/weevil]

Year	Weevil strain	LD_{50}	LD_{90}
1968	Control zone	0.69	1.77
1968	Check zone	.63	1.62
1971	Control zone	.42	.90
1971	Check zone	.41	.79
1973	Control zone	.51	.90
1973	Check zone	.46	.99

[1] Data from 1968 and 1971 taken from Bottrell et al. 1973. J. Econ. Entomol. 66: 791–792.

programs based upon the late-season suppression of potential overwintering weevils in combination with short-season cotton, resistant varieties, and pheromone trapping systems.

There is a need for more research on diapause in the boll weevil. Diapause is one of the least understood and most important phenomenons in the seasonal biology of the insect. More information is needed relating to the time of entry of diapausing weevils into hibernation and the survival rate of weevils entering hibernation at different times during the season. Also needed is a technique to achieve a more quantitative and reliable value to index the status of diapausing weevils.

With present techniques we have had considerable success in exploiting the overwintering period as a "weak link" in the seasonal cycle of the boll weevil. Additional research should allow us to develop even more effective techniques for the control of potential overwintering weevils.

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GRANDLURE DEVELOPMENT

By P. A. Hedin[1]

The initiation of chemical work on grandlure was made possible by a series of observations and developments. Cross and Mitchell (1966) first showed in 1963 that females responded to males in the field from distances greater than 30 feet while males were found not to respond to females over distances greater than 3 to 5 cm. Subsequently, Keller et al. (1964) reported that a substance attractive to female boll weevils in the laboratory could be collected by drawing air over males, passing the air through activated charcoal, and extracting the charcoal with chloroform. Hardee et al. (1967) then developed a laboratory olfactometer in which females responded to males, but not males to females. This olfactometer was subsequently used during the chemical studies which led to the identification of the pheromones.

In the initial chemical work, extractions of males with dichcloromethane produced a substance that was consistently attractive to females, but a similar extract of mixed insects was unattractive to females. When the male extract was steam-distilled, the solvent extract of the distillate proved to have greater attractiveness for females than any of the other extracts that had previously been prepared. Assays of the steam distillate in concentrations as low as one male equivalent, and simultaneous assays of live males, indicated that approximate quantitative removal of the attractant had been obtained. When the frass of males, and later, mixed sexes was steam-distilled, it also was highly attractive to males (Tumlinson et al. 1968). Because the frass could be collected from the mass-rearing facility, which was primarily being used for the production of sterile males, over 50 kg was eventually obtained and processed for isolational work at only a nominal direct cost. However, it is estimated that 6 million additional insects were used for this work.

Our next step was to fractionate the distilled extract on a silica gel chromatographic column. The activity could not be found in any single fraction, but returned on recombination of two of the fractions. Thus, we were faced with elucidation of a multicomponent mixture. Considerable removal of nonactive components was achieved by chromatographing the two active fractions on silica gel silver nitrate columns and then bioassaying appropriate fractions in combination until activity was demonstrated again. Gas chromatography was then used to separate the two alcohol components which could not be separated by column chromatography.

Now we knew of three separate components which had to be present for activity. Later, on an open tubular column, we were able to separate the *cis* and *trans* forms of the aldehyde, at which time we realized that four components were required.

With a few milligrams of each of the alcohols, analyses by IR, NMR, and MS, data was obtained which, with some other data, allowed us to deduce the structures of the alcohols.

Only microgram quantities of the aldehydes were isolated. The major evidence for their structures was obtained by mass spectrometry. Derivatization and reaction studies showed we were dealing with an aldehyde similar to compound II. Thus, we now postulated four structures, which are given in figure 1. They are I. (+)-*cis*-2-Isopropenyl-1-methylcyclobutaneethanol; II. *Z*-3,3-dimethyl-$\Delta^{1,\beta}$-cyclohexaneethanol; III. *Z*-3,3-dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde; and IV. *E*-3,3-dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde.

We next commenced synthesis of the three six-membered ring components, which, when achieved, provided proof that our postulations

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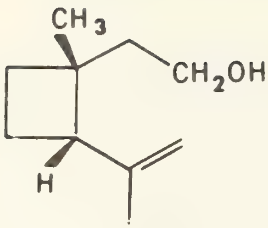

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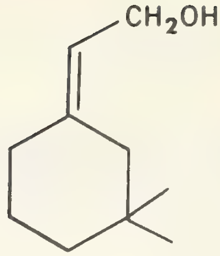

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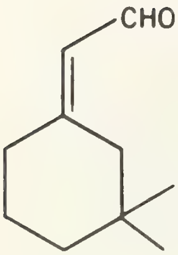

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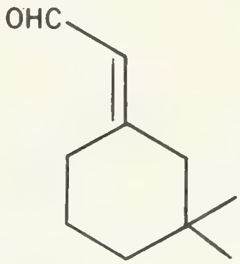

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FIGURE 1.—Compounds. I, (+)-*cis*-2-Isopropenyl-1-methylcyclobutaneethanol. II, *Z*-3,3-Dimethyl-$\Delta^{1,\beta}$-cyclohexaneethanol. III, *Z*-3,3-Dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde. IV, *E*-3,3-Dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde.

had been correct, because the spectral data matched that of the natural components and, more importantly, because the synthetic components successfully replaced the natural ones in the bioassay. The cyclobutane alcohol was a rather unusual structure because of its four-membered ring, and it was difficult to synthesize with the appropriate substituents because four-membered rings are strained, and thus difficult to close.

After two unsuccessful attempts, a third was made which involved using a photochemical reaction to close the ring. This succeeded and after several more manipulations, a mixture was obtained which was expected to contain the desired component. The several components were separated by gas-liquid chromatography and each examined until we located one which was very similar in its chemical and spectral properties to what we were looking for. When we tested it with the other components, the mixture was not active. On increasing the concentration, however, activity was achieved. We went back to the mixture and isolated another isomer which was 200 times more active when combined with the other components. Thus, we had finally confirmed that the structures we had postulated were as active as the natural ones in the bioassay.

During the next few months, R. C. Gueldner of this laboratory developed a better synthesis of grandisol which has served for the synthesis of several hundred grams of this compound by us and various vendors.[2] During the next year, we synthesized about 75 g of each compound for field tests. It became apparent that we neither had the capacity, nor was it the best use of our time to continue routine synthesis work, so we prevailed on U.S. Department of Agriculture and other groups to provide money for custom synthesis. This path to procurement has not always been smooth, however. In fact, several vendors who were either unqualified or did not take our advice seriously, defaulted. Ultimately, several reliable vendors were identified and we have worked smoothly with them during the last 4 years.

It was also important to interest outside groups in our work, because we knew that acceptance of the pheromones throughout the Cotton Belt would occur only with availability from common sources and with volume use.

An associated problem has been formulation. Because the components are more volatile and more reactive than some of the moth pheromones, they have been more difficult to formulate as active preparations for extended periods. For 2 or 3 years, we had to endure speculations about whether we really had solved the problem and whether grandlure was not as potent as the moth pheromones for these reasons. Fortunately, development of various keepers or extenders, dispensers, effective traps, and effective use of traps has shown that under proper use, the pheromone performs very effectively. While this work has been done largely by McKibben, Cross, Hardee, and others, our contributions were involved with suggestions about keepers, release barriers, and quality control.

[2] It is not the purpose of this report to give the details of the chemical work, but the following references are included for those who may find this information of interest. The original isolation, identification, and synthesis was reported by Tumlinson et al. (1969). An extended report on the original synthetic work was also published by Tumlinson et al. (1971), and an improved synthesis of grandisol was reported by Gueldner (1972).

In recent work, we have attempted to assess the lifetime pheromone biosynthesis potential of the male boll weevil. We found that the production of the pheromones by the male is very limited for the first 5 days after emergence. The production reaches a maximum at 8 to 10 days, and the male continues to biosynthesize the pheromones at about the maximum rate for the next 20 days. The total content of the pheromones in the male is never greater than about 200 nanograms, but the average content in the frass produced during one day is about 1,300 nanograms, and the lifetime production is at least 40,000 nanograms. The ratio of the four components in frass is 6:6:2:1/I:II:III:IV. None of the four components was ever found in females and only traces were found in female frass in three instances. This production is perhaps 1,000 times that of moths, but less than that of some of the larger Coleoptera, such as the bark beetle.

In retrospect, this research program required about 5 years (1966–71) to bring it to the developmental stage. Rough calculations allowing for salaries, insects, equipment and supplies, and overhead suggest the research may have cost $800,000–$1 million. At present, efforts are being directed toward the improvement of the synthetic procedures to reduce cost, toward interesting additional industrial groups in production synthesis and formulation, and toward providing sufficient quantities of the components for toxicological studies, so that the compounds may be registered and approved for field use. Other studies are being made to determine whether the female attracts the male, or perhaps deters other females from ovipositing in the same bud. The ability of males from various geographical locations, in diapause, in crowded rearing facilities, etc., to produce pheromone is also being evaluated.

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DEVELOPMENT OF BOLL WEEVIL TRAPPING TECHNOLOGY

By D. D. Hardee[1]

As early as 1902 entomologists attempted without success to trap boll weevils, *Anthonomus grandis* Boheman, with cottonseed meal, light, and molasses (Hunter and Hinds 1905). Adhesive-coated elevated flight screens have been used for 45 years to capture boll weevils and study their dispersal (Fenton and Dunnam 1928; Taft and Jernigan 1964). In 1965 unsuccessful attempts were made (Hardee, unpublished) to capture boll weevils in Alabama, Louisiana, and Mississippi on adhesive-coated wooden traps baited with a cotton plant extract shown attractive in laboratory bioassays (Hardee et al. 1966). Trapping of boll weevils as we know it today actually has evolved in the last 10 years as a result of the observations in 1963–64 by Cross and Mitchell (1966) that a windborne pheromone for female boll weevils was released by males. These findings, along with the confirmation of sex attraction by Keller et al. (1964) in the laboratory, stimulated a series of experiments and programs over the next 6 years (summarized by Hardee 1972) which culminated in the use in 1971–73 of pheromones and traps as one of the suppression measures in the Pilot Boll Weevil Eradication Experiment (PBWEE) (Knipling 1971, Hardee 1974). The chronological order of the most significant events toward progress in pheromone and trap research on boll weevils is summarized in table 1. For the purposes of this paper, I should like to summarize five trapping experiments in 1968–69 which provided the evidence for including pheromone traps as one of the suppression measures in the PBWEE (table 2).

Research has shown conclusively that one essential prerequisite for the efficient operation of the pheromone trap principle in suppression is the reduction of overwintered boll weevils to less than 25–50/acre before using traps. This can be effectively accomplished with reproduction-diapause control in late season in a total area that is isolated, or in greater acreage on an areawide basis. Such an extensive area is the High Plains of Texas where each fall, beginning with 1964 (Adkisson et al. 1965), cotton acreage has been treated extensively with insecticides for control of the boll weevil with funds supplied jointly by the farmers, collected and administered by the Plains Cotton Growers, Inc., and the U.S. Department of Agriculture. This program, which is an attempt to prevent the spread of the boll weevil into the highly productive irrigated cotton above the Caprock, has been extremely effective in reducing the number of surviving overwintering boll weevils in the control zone.

In 1968 the first attempts were made to influence developing field populations of boll weevils with traps and to measure the potential of male-baited wing traps (Cross et al. 1969) in survey and suppression of boll weevils. Traps were placed around nine fields in Dickens, Kent, and Crosby Counties (inside the control zone) and around one field in Stonewall County (near Aspermont) in the center of an area heavily infested with boll weevils. By May 18 boll weevils had been captured around all but three fields, some in extremely high numbers, and by June 25 the remaining three fields were also positive. This is extremely significant in view of spring surface woods trash examinations from the control zone, which had yielded only one live boll weevil from 600 yd^2 of trash.

From these original 10 fields, 3 were selected for intensive trapping and study (4–5 traps/acre): 2 fields located 10 mi southwest of Spur (Kent County) inside the control zone, and 1 field in a heavily infested area 8 mi north of Aspermont (outside the control zone). The results of this test (Hardee et al. 1970) showed that significantly more boll weevils were captured

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TABLE 1.—*Chronological order of significant events in research on pheromones and traps for boll weevils*

Year	Finding	Reference
1963	Males attract females in field	Cross and Mitchell (1966).
1964	Males attract females in laboratory	Keller et al. (1964).
1965	Development of laboratory bioassay	Hardee et al. (1965).
1966	Development of wing trap	Cross et al. (1969).
1966	Initial field studies with traps	Hardee, Cross, Mitchell, et al. (1969).
1966	Preliminary chemical isolation	Tumlinson et al. (1968).
1967	Males attract both sexes in field	Bradley et al. (1968), Cross and Hardee (1968), Hardee et al. (1969).
1968	Survey and control with male-baited traps	Hardee et al. (1970).
1968	Long-range dispersal confirmed	Davich et al. (1970), Ridgway et al. (1970).
1968	Identification and synthesis of grandlure	Tumlinson et al. (1969).
1969	Large-scale suppression with male-baited traps	Boyd et al. (1973), Coppedge and Ridgway (1973), Hardee et al. (1971), Lloyd, Merkl, et al. (1972).
1969–70	Grandlure active in nature	Hardee, McKibben, et al. (1972).
1969–70	Discovery of flourescent colors for traps	Cross et al. (1974), Hardee, Cross, et al. (1972).
1969–70	Development of trap-crop principle	Boyd et al. (1973), Coppedge and Ridgway (1973), Hardee et al. (1971), Lloyd, Scott, et al. (1972).
1970	Field usage of formulated grandlure	Hardee, McKibben, et al. (1972).
1970	Development of Leggett trap	Leggett and Cross (1971).
1970	Use of male-baited wing traps in eradication	Coppedge and Ridgway (1973).
1971–72	Development of improved formulations and ratios of grandlure	Bull et al. (1973), Hardee, Graves, et al. (1974), Hardee, Rummel, et al. (1974), McKibben et al. (1974).
1971–73	Use of Leggett traps and grandlure in Pilot Boll Weevil Eradication Experiment	Knipling (1971), Hardee (1974).
1973	Development of in-field trap principle	Mitchell and Hardee (1974).

per acre in the untreated field than in the treated fields, and that development of the population in the treated fields was delayed in comparison to that in untrapped fields in the area until migration of boll weevils from untreated fields 2 mi or more away overpowered the traps. A good indication of the potential of a few traps in reducing early buildup of boll weevils in a cottonfield can be obtained by examining the results of trapping 36 acres of irrigated cotton located 2 mi southwest of Girard (inside the control zone). Twelve survey traps placed around this field captured 163 overwintered boll weevils between April 27 and July 9. No weevils were captured between July 10 and August 13. During the period August 14–September 17, 48 weevils were captured. In weekly manual surveys from June 10 through August 30, live weevils were found in the field only once (during the week of July 15), and punctured squares remained less than 10% until the week of August 5. Untrapped fields in the immediate vicinity of the trapped field had 10% or greater punctured squares as early as July 8 and as high as 6,000 boll weevils per acre in August 19–23.

During this test and others conducted in 1968 in Texas and Mississippi, we discovered several things that influenced the initiation of future trapping programs against boll weevils. First, brighter colored, male-baited traps were much more effective in capturing boll weevils than the dark green traps used in 1968 (Hardee, Cross, Mitchell, Huddleston, and Mitchell 1972, Cross et al. 1976). Secondly, since long-range migration of boll weevil is a common occurrence, without isolation from heavily infested cotton, or maintenance of a buffer zone of low-level populations around the test area, migration of dispersing boll weevils into the test field can overwhelm the males in traps and mask any effect the traps might have on developing populations. Boll weevils were trapped in West Texas in the spring of 1968 at least 6½ mi from the nearest cotton (Ridgway et al. 1971), and in Mexico in the fall of 1968 at least 45 mi from cotton (Davich et al. 1970). Thirdly, male boll weevils require almost a continuous supply of fresh food (preferably cotton squares) for maximum pheromone production (Hardee 1970), and fresh squares as provided in the 1968 tests were dehydrated within 24–48 h, and provided a very poor source of food for production of pheromone.

The success achieved in 1968 in spite of the three factors just mentioned stimulated the execution of a massive trapping effort in 1969 in two areas. Attempts were made to overcome these factors in the following ways: (1) Metal traps painted yellow were used instead of the 1968 dark-green plywood traps, (2) males were fed cotyledons in aquapicks containing water, rather than in screen boxes containing squares, because large numbers of cotton squares were not available and squares dry out very rapidly in the hot sun, leaving the male with inferior food from which to produce pheromone, and (3) a larger area was trapped in an attempt to decrease the amount of migration into the area by boll weevils dispersing from untreated cotton.

The Rolling Plains of Texas, just east of the Caprock, was again selected as one of the test areas. This area was the site of three separate trapping efforts, all of which had been preceded by a reproduction-diapause control program the previous fall.

The largest trapping effort (Boyd et al. 1973) extended 60 mi north to south and 30 mi west to east. Approximately 26,500 traps were placed in this area, comprising approximately 75,000 acres, about the time seed was planted. The traps were placed around each field with higher numbers located adjacent to potential hibernation sites rather than in large open areas.

Trap crops consisting of one or two 50-ft rows of cotton grown at the laboratory, then transplanted into the field between April 22–30, were located at the field edges, and were treated with aldicarb. This measure was taken in an attempt

TABLE 2.—*Summary of trapping experiments with male prior to PBWEE*

Year	Location	Agency[1]	Objectives	Acres	Traps	Trap crops	Results[2]	Reference
1968	West Texas.	ARS	Survey, suppression.	90	260	No	1. Traps excellent for survey. 2. More effective in low population area. 3. Delayed buildup.	Hardee et al. (1970).
1969	....do	APHIS	Suppression (large-scale).	75,000	26,500	Yes	1. Difficult to assess. 2. Weevils localized. 3. Trap crops ineffective.	Boyd et al. (1973).
1969	....do	ARS	Eradication	273	456	Yes	1. Traps removed 9.5 bw/acre. 2. No live weevils before 9/1. 3. Survivors—1 bw/100 acres.	Coppedge and Ridgway (1973).
1969	....do	ARS	Suppression, trap placement.	1,542	1,542	Yes	1. Traps around fields + trap crop best treatment. 2. 17 of 34 fields no bw in field, all 34 bw on traps.	Hardee et al. (1971).
1969	Mississippi	ARS	Suppression, trap density.	4,000	5,000	No	1. Efficiency greatest at low density. 2. 1, 2, 4, 8 traps/acre—bw/trap equal. 3. 1, 2 traps/acre—fewer bw/acre in field than with 4, 8 traps/acre.	Lloyd, Merkl, et al. (1972).

[1] ARS, Agricultural Research Service. APHIS, Animal and Plant Health Inspection Service.
[2] bw, boll weevil.

to entice those weevils that might be out of range of a pheromone trap, or might not respond immediately to a pheromone trap, to feed on the early fruiting cotton and be killed by the insecticide. The objective was to suppress boll weevil populations to as low a level as possible and, it was hoped, to reduce or eliminate the need for a diapause control program in the fall of 1969. These traps were serviced once a week from April 20 to July 25.

A total of 10,159 boll weevils was captured with these traps, 84% of which were caught between May 25 and June 21. Since only 14.7% of the 26,500 traps caught all of the boll weevils, and 65.1% of the weevils were caught in integrals of 2 or more, hibernation of weevils was localized, and they emerged in relatively large numbers over a short time interval.

Because of logistical problems encountered (particularly in servicing the traps), budgetary constraints, and lack of an efficient and economical method of detecting and measuring accurately low-level populations of boll weevils, it was impossible to assess with confidence the full impact of eliminating 10,159 boll weevils from the area. Information was obtained, however, which showed the distribution of boll weevils in the spring, which showed that low-level populations occurred in most of the treated area, and which pointed to some of the logistical problems with which it would be necessary to contend in future tests. It was concluded (Boyd et al. 1973) that the use of aldicarb-treated trap crops of transplanted cotton is impractical in west Texas under the conditions of this test because soil moisture and wind conditions presented problems that could not be solved from the standpoint of economics or practicality.

A second trapping effort in West Texas was conducted on 273 acres of cotton in the middle of ranching country in King County at least 13 mi from the nearest cotton (Coppedge and Ridgway 1973). Treatments on this farm included reproduction-diapause control in the fall of 1968, trap lines to monitor boll weevil movement, one to two traps per acre of cotton (around and inside the field), applications of aldicarb to the entire acreage at planting (1 lb/acre in-furrow) and at squaring (3 lb/acre sidedress), and five foliar applications of insecticide between July 28 and September 6 to control *Heliothis* and other pests. Sampling by various means of nearly 60 acres of cotton in June, July, and August failed to detect live boll weevils in the cotton. However, six oviposition-punctured squares were found within a 0.04-acre area during the first 2 weeks in August, but dissection of these revealed no evidence of eggs or developing larvae. Live boll weevils were detected after September 1, which is subsequent to late-season dispersal which occurs in the area (Ridgway et al. 1971). Coppedge and Ridgway (1973) state that though the contribution of traps to suppression in this experiment was difficult to assess for various reasons, they did remove a substantial number of boll weevils from the population (9.5 boll weevils per acre of cotton) and thus contributed significantly to the total suppression effort. In addition, the pheromone produced by the caged males may have confused any possible surviving weevils and made it difficult for them to find a mate. The evidence of an unmated female in the cotton appears to substantiate this possibility.

The third trapping effort in West Texas in 1969 was inside the 75,000-acre test area described earlier and involved a detailed study on the effect of trap placement and the value of aldicarb-treated and untreated trap crops on boll weevil suppression (Hardee et al. 1971). This study involved 34 fields, 1,542 acres, and 6 replications of the 6 following treatments: (1) One trap per acre around each field, (2) one trap per acre in each field, (3) one-half trap per acre around, plus one-half trap per acre in, each field, (4) one trap per acre around each field with an untreated trap plot, (5) one trap per acre around each field with an aldicarb-treated trap plot, and (6) one trap per acre around each field in three tiers.

The trap crops were transplanted cotton which received one application of aldicarb granules at the rate of 4 lb/acre of active material in-furrow at the time of transplanting, and 4 to 6 weeks later a second application at 4 lb/acre as a sidedress treatment.

When trap removal was completed on August 29, boll weevils had been captured on traps around all 34 fields (some in relatively high numbers), but no sign of boll weevils had been found in 17 fields. Live boll weevils were found in 7 and egg-punctured squares in 10 of the 17 infested fields. The data suggest that traps located around fields and traps tiered around fields gave better results than traps located in the fields, and that systemic-treated trap crops were superior to untreated trap crops. Estimates of percentage of suppression by the different treatments were calculated on an individual field and treatment mean basis by dividing the number of boll weevils trapped per acre by the number of boll weevils trapped per acre plus the number found per acre in field surveys. Assuming 100% efficiency of the sampling methods, suppression of all treatments was over 70%.

A fourth, large-scale boll weevil trapping effort was conducted in eastern Mississippi, in the Tombigbee River Valley (Lloyd, Merkl, Tingle, Scott, Hardee, and Davich 1972). This effort was preceded by two voluntary grower-sponsored reproduction-diapause control programs in 1967 and 1968 and included all cotton plantings in an area 8 mi north to south and 5 mi east to west, an area containing approximately 4,000 acres of cotton. Five thousand traps were placed around the fields between April 3 and April 26, 1969. A part of this trapping effort was a trap density study which included six replications of one, two, four, and eight traps per acre placed around the fields.

Lloyd, Merkl, Tingle, Scott, Hardee, and Davich (1972) concluded from this study that trap efficiency was inversely related to population density. Where overwintered boll weevils numbered less than 5 per acre, trap efficiency was estimated to be 93%, but decreased to 21% when populations were about 300 per acre. Overwintered boll weevils were not detected in 58% of the fields in the trapped area during June; 11% of the fields were estimated to have populations numbering 13 overwintered weevils per acre, 14% had 26 per acre, 3% had 39 per acre, and 14% had more than 50 overwintered weevils per acre. The larger populations were found in and near fields where growers did not participate in the 1968 reproduction-diapause control program. Outside of the trapped area, the overwintered boll weevil population in 6 fields averaged 254 weevils per acre on June 9. Differences in the number of overwintered boll weevils collected per trap were not significant when one, two, four, and eight traps per acre were compared, but there were more weevils per acre in the field when there were eight traps per acre around it than when there were only four traps per acre around the fields. Similarily, there were more weevils in fields which had four traps per acre than in fields which had one or two traps per acre around them. Under the conditions of this experiment, there appeared to be no difference in numbers of overwintered boll weevils in the field when fields had either one or two traps per acre.

Lloyd, Merkl, Tingle, Scott, Hardee, and Davich (1972) concluded that where growers had reduced the size of the boll weevil population the preceding fall, the use of wing traps had a marked effect on the boll weevil population in the experimental area. Under these situations traps effectively removed these small populations before they infested the fields in the spring to the extent that they eliminated the need for control measures for boll weevils or bollworms until the appearance of the second field generations of boll weevils in early August.

In summary, these five trapping experiments illustrate that even with somewhat inefficient procedures, male-baited traps effectively removed a portion of overwintered boll weevils from a developing population and thereby provided a degree of suppression sufficient to justify inclusion of the trapping principle as one of the suppression measures in the PBWEE. Subsequent to these experiments several improvements made the trapping principle even more efficient. One of these was the development of the Leggett trap (Leggett and Cross 1971), which is considerably more effective in most areas than the types of wing traps used in 1968–69. Secondly, identification and synthesis (Tumlinson et al. 1969) of grandlure, the four components of the boll weevil pheromone, which was shown effective for 2 to 3 days in nature in short-lived formulations (Hardee, McKibben, Gueldner, Mitchell, Tomlinson, and Cross 1972), and later for 10 to 14 days in slow-release formulations (Bull et al. 1973; Hardee, Graves, McKibben, Johnson, Guelder, and Olsen 1974; and McKibben et al. 1974), alleviated the need for the use of live males in traps. This insures a continual source of effective pheromone without the logistical deterrents of rearing and feeding of live insects, a known inferior source of pheromone. Manipulation of ratios of the components of grandlure in 1972 tests more than doubled its effectiveness (Hardee, Rummel, McKibben, Huddeston, and Coppedge 1974) over the standard ratios. Thirdly, the development this past season of the in-field trap principle (Mitchell and Hardee 1974) adds a new dimension to the possibilities of survey and suppression of low populations of boll weevils by being effective in midseason when peripheral sticky wing traps or Leggett traps become ineffective. These improvements in the general trapping principle, plus the success achieved in suppression of boll weevils with traps in 1968–69 and in the PBWEE, suggest a very important role for traps and grandlure in future programs of survey, management, and elimination of the boll weevil.

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TRAP CROPS FOR BOLL WEEVIL CONTROL

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The use of small plantings of a preferred host as a trap crop has long been suggested as a means of protecting the main planting from severe injury from specific insect pests. Two basic methods of trap-cropping may be used. First, a preferred host may be planted to protect a less preferred main crop. For example, corn can be planted adjacent to cotton to reduce bollworm, *Heliothis zea* (Boddie), damage to the cotton. Secondly, a small portion of the principle crop can be manipulated to provide a trap crop that will protect the remainder of the planting. Cotton is the preferred, and in most instances, the only host of the boll weevil, *Anthonomus grandis* Boheman. Thus, in considering trap crops for boll weevil control, we are limited to the second method of trap-cropping.

The possibility of trap-cropping for boll weevil control was recognized soon after this pest entered the United States. L. O. Howard (1896) suggested that overwintered weevils could be concentrated on early-planted or volunteer cotton and then collected by hand or poisoned. Despite a few negative reports, (Hunter 1909, 1917), most early researchers found that early-planted trap crops of cotton were a very effective means of concentrating emerging overwintered weevils. However, in most instances, trap crops were not used for boll weevil control; instead, they were used in studies of boll weevil hibernation, winter survival, spring emergence, and dispersal (Fenton and Dunnam 1927, 1928; Bondy and Rainwater 1942; Fife et al. 1950; Beckham and Morgan 1960; Parencia et al. 1964; Walker 1966).

Isely in Arkansas was the most notable early proponent of trap-cropping as a boll weevil control measure. In 1924 Isely pointed out that the initial boll weevil infestation was almost always restricted to a very small part of a cottonfield, usually in corners or along the margins of fields. Thus, Isely reasoned, there was no advantage in treating the entire field for these localized infestations. He suggested that whole-field applications dissipated manpower and insecticide resources instead of concentrating these resources where needed.

Accordingly, Isely recommended "spot dusting" to destroy early boll weevil infestations and to retard their spread. Later he reported (1926) that spot dusting was very successful when the area of early infestation could be defined. However, locating and delimiting the area of the early infestation often proved difficult. It was known that a greater number of overwintered weevils could be expected on the taller cotton plants than on shorter plants in the same field (Ballard and Simpson 1925). Thus, Isely (1950) suggested that small trap crops of cotton be planted earlier than the main planting. Field test results verified Isely's idea. Trap crops that were distinctly earlier than the main planting concentrated the early boll weevil infestations so they could be easily found and treated.

Despite these and other observations, there was relatively little research with the trap-crop technique for boll weevil control until recent years. Bradley (1967), working in Louisiana, found that overwintered boll weevils could be expected to congregate in early-planted border strips, provided that the difference in planting dates was sufficient to give a distinct advantage in height to the trap plants. Periodic treatment of the trap crops with foliar sprays of methyl parathion deterred the buildup of damaging infestations of boll weevil in the remainder of the field until midseason. Bradley (1967) and later Benkwith (1971) also found that trap crops of

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susceptible strains of cotton amplified the effectiveness of main plantings of strains with nonpreference resistance characteristics.

The discovery that male boll weevils emit a windborne aggregating pheromone (Keller et al. 1964, Cross and Mitchell 1966) has had important implications for the potential value of trap-cropping for this pest. Hardee et al. (1969) suggested that emerging overwintered male boll weevils initially locate cotton by random movement, feed, and emit the aggregating pheromone that attracts other migratory weevils to the field. Lloyd and coworkers recognized the potential of the male-produced pheromone to increase the effectiveness of trap crops. Their experiment (Lloyd et al. 1972) involved an integrated system wherein sterilized male boll weevils were confined on plants adjacent to rows of aldicarb-treated cotton. They suggested that the aggregating pheromone produced by the confined male weevils would attract emerging overwintered weevils to the plants treated with the systemic insecticide, where they would be killed. Their data indicated that the system would be effective, especially against low-density populations of over-wintered boll weevils.

The identification and synthesis of the male-produced phromone, grandlure (Tumlinson et al. 1969), incrased the feasibility of using the pheromone in a trap-crop situation for boll weevil control. Thus in 1972, as part of the peripheral research program being conducted in conjunction with the Pilot Boll Weevil Eradication Experiment, we conducted tests to determine the effctiveness of the trap-crop system employed in the eradication experiment (Boyd 1973).

Methods and materials—A four-row trap crop of an early-fruiting cotton variety ('Quapaw') was planted in each of nine cottonfields in Covington County, Miss. Each trap crop was planted 2 to 3 weeks prior to the remainder of the crop. Aldicarb at 1.0 lb active/acre was applied in-furrow at planting. At the pinhead square stage, about 6 weeks after planting, additional aldicarb was applied to the trap crop as a side-dress application at 2.0 lb active/acre. The nine fields used in this test treatment were located in the first buffer zone of the eradication experiment area, and had received a 13-application reproduction-diapause control program during the fall of 1971. Pheromone-baited traps (Leggett and Cross 1971) were maintained around each field as part of the operational procedure of the eradication experiment (Boyd 1973). Also, pheromone bait stations, consisting of one unit of the formulated boll weevil aggregation pheromone, were placed at about 200-ft intervals in each trap plot. The pheromone traps and bait stations were rebaited weekly.

In nine other fields located about 10 mi away in Smith County, a somewhat different trap crop system was implemented. In these fields the trap crops received aldicarb in the same manner as described above, but were planted only 2 or 3 days prior to the remainder of the field. These 10 fields were located in the second buffer zone of the eradication experiment; they received only eight reproduction-diapause control treatments the previous fall. Also, no pheromone traps were maintained around the fields, and no pheromone bait stations were maintained in the trap crops.

Boll weevil infestations in the trap crops and regularly planted portions of the fields were monitored weekly from late April through late July; whole plant counts were taken from late April until termination of the experiment in late July. From mid-June until termination of the test, additional sampling was conducted with a mechanical sampler mounted on a high-clearance spray machine (McCoy 1971). Boll weevil damage in the various fields was assessed by counting the number of oviposition-damaged squares.

Results and discussion.—Whole-plant counts indicated that the early-planted trap crops were very effective in attracting overwintered weevils that missed the pheromone traps and entered the fields. No boll weevils were found in whole plant samples in the nontreated regular plantings in Covington County fields, while samples from the trap crops indicated relatively large weevil populations in early July. In the Smith County fields there was no appreciable difference in weevil populations in the trap crops or regular crops until early July. During July weevil populations in both crops reached relatively high numbers.

Samples collected with the mechanical sampling machine confirmed the effectiveness of the trap crops in Covington County and the relative ineffectiveness of the Smith County trap crops (table 1). Boll weevil damage estimates based

TABLE 1.—*Estimated populations of boll weevil in trap crops and regularly planted portions of cottonfields, Covington and Smith Counties, Miss., 1972*

Location and date	Avg. No. weevils/acre[1]	
	Trap crop	Regular crop
Covington County:		
June 14	14	7
June 22	72	0
June 28	14	9
July 8	55	6
July 19	46	9
Smith County:		
June 15	0	0
June 21	0	0
June 28[2]	...	...
July 5	19	19
July 20	78	69

[1] Based on samples collected with mechanical sampling machine.
[2] Counts not made.

TABLE 2.—*Counts of boll-weevil-infested squares in trap crops and regularly planted portions of cottonfields, Covington and Smith Counties, Miss., 1972*

Location and date	Avg. % oviposition (punctured squares)	
	Trap crop	Regular crop
Covington County:		
June 14	0.0	0.1
June 22	0.5	0
June 28	4.9	0
July 5	4.2	1.4
July 13	10.0	2.6
July 21	8.7	3.7
Smith County:		
June 14	.0	.0
June 21	.0	.0
June 28[1]	....	...
July 6	8.1	7.1
July 12	6.5	5.4
July 19	16.7	15.8

[1] Counts not made.

on counts of oviposition-punctured squares further verified the disparity in effectiveness of the two trap crop systems (table 2).

Differences in effectiveness in the Covington and Smith County trap-crop systems were attributed to planting date intervals for the trap crops and the presence or absence of pheromone traps and bait stations. Cotton plants in the Covington County trap crops were noticeably taller and more mature than the regular plantings until mid-July, while differences between the trap crops and regular crops in Smith County were less obvious. The pheromone bait stations in the Covington County trap crops undoubtedly enhanced the attractiveness of the trap crops; almost all weevils located by whole-plant sampling prior to F_1 emergence were found within 15 ft of a bait station. Thus, the lack of a plant height differential between plants in the trap crops and regular crops in Smith County, and the absence of pheromone bait stations greatly reduced the attractiveness of these trap crops for emerging overwintered weevils.

In summary, it is apparent from these data that trap crops were an effective means of concentrating and suppressing emerging boll weevil populations if the trap crops were planted earlier than the main crop, and if pheromone bait stations were used.

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BOLL WEEVIL RESISTANT COTTON VARIETIES

By Johnie N. Jenkins[1]

Research in host plant resistance has been emphasized from the beginning at the Boll Weevil Research Laboratory (BWRL) in Mississippi. We[2] have found a number of cotton lines with various degrees of boll weevil resistance. This report, however, concerns itself only with one character for resistance, Frego bract. From a genetic standpoint, this morphological trait is the easiest to work with of all the traits we have found. It is also the one that has the greatest potential at the present for near-immediate use in variety development. Though it has been tested more extensively than anything else we have found, it is not the only source of boll weevil resistance with which we are working.

Frego bract has bracts that are narrow, twisted, and rolled, rather than flat and wide and enclosing. It was first reported as having potential resistance to the boll weevil by Hunter et al. from their work in Arkansas in the late 1950's. They, however, reported that it was not of itself sufficient to be used alone as a control method for boll weevil. The development of the reproduction-diapause control concept and the renewed interest in integrated control caused us to believe that research was needed with Frego bract. Our small plot data for 3 years in mid-1960 led us to postulate that Frego bract should be an effective component of an integrated control program. We thus began to develop research ideas to determine the value of Frego bract for possible use as a trait for boll weevil resistance.

In addition to our work at the BWRL, we have been cooperating with J. E. Jones and D. F. Clower of the Agronomy and Entomology Departments respectively, at Louisiana State University (LSU), who have conducted a great deal of research with Frego bract. They have explored the use of Frego bract with normal strips interplanted, and the use of insecticides for boll weevil control only on the normal bract strips. Their results are very interesting and promising, but space does not permit me to report on any of their work in this area. They have also conducted some experiments with Frego bract alone, with results similar to ours. All the results reported herein will be from research conducted by use at the BWRL except the yield and fiber data which were done by J. E. Jones at LSU.

Some work by W. H. Cross at the BWRL shows the modifications of behavior which the boll weevil exhibits when it is on Frego bract cotton. Our field experiments suggested that this research was needed. Table 1 shows where female boll weevils were found in normal bract and Frego bract cotton when radioactively tagged weevils were extensively studied in the field. As you will note, 74% of the weevils were found in the squares in normal bract, whereas only 19% were found in the squares in Frego bract. The various percentages of location indicate where the weevils are spending their time. On Frego bract weevils were as often found on leaves and stems, and more often found on the terminals, than on the squares. In addition, the weevils appeared nervous and frustrated on the Frego bract cotton.

Table 2 shows additional data on the activity of the boll weevils on normal and Frego bract cotton. The 50% reduction in eggs per hour on Frego is significant. There was also a longer time required for feeding and oviposition. Much more plant-to-plant movement (eight times more) was found in the weevils on Frego bract. There are many ways that this movement, in particular, may be beneficial to us in an inte-

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[2] F. G. Maxwell was entomologist the first 7 years; W. L. Parrott has been entomologist for the past 6 years. I have been plant geneticist throughout.

grated control program. For example, the increased movement may make the weevil more likely to contact a lethal dose of a residual insecticide on Frego bract plants than on normal ones. Weevils may respond to in-field or out-field traps more readily in Frego bract cotton. These behavior modifications help explain the resistance we have obtained in all field experiments.

Table 3 shows in summary form the results of our field experiments in the past 3 years with Frego bract. In 1970 we had four experiments in four counties in Mississippi. Each experiment involved approximately 10 acres of Frego and an equivalent acreage of normal bract on the same farm. The suppression of the population varied from 66% to 94%, and was dependent upon the initial level of weevils that overwintered. Weevils in all fields of Frego and normal bract were kept below the economic threshold with the exception of those in the normal in experiments B and D. In these experiments normal bract was allowed to develop a higher infestation than in A and C. The best suppression was in field C, where no insecticides were necessary for boll weevils in the Frego bract and the population suppression was 94%. The overwintering level of weevils was very low in the normal and Frego bract.

In 1971 we ran three experiments, each with three or four replications each. There were 3 acres of Frego bract in each replication. An adjoining field of normal bract was paired with each Frego bract field or replication. The suppression ranged from 29% to 79%. The highest level of overwintering weevils was in experiment G, and the lowest in F. Experiment E was on the farm of a grower who sprayed everything in a 5- to 7-day schedule from emergence to maturity, and thus there were not many weevils present in either Frego or normal bract. Even then Frego showed fewer eggs oviposited per acre than normal.

The largest experiment we conducted was in 1972, and is shown as experiment H. This experiment was in Copiah County, Miss., and was conducted in the research phase of the Pilot Boll Weevil Eradication Experiment. We obtained a 50% suppression of boll weevil egg-damaged squares per acre and a 46% reduction in the use of insecticides.

Figure 1 details the 1972 experiment. We worked on two grower-cooperators' farms in the Carpenter community. We were in the area that did not receive the full diapause program in 1971. We had 12 fields (replications) of Frego bract and 12 of normal bract. We took records and managed the insects and insecticide applications on all the cotton the two growers had on

TABLE 1.—*Location of female boll weevils observed on Frego and normal bract cotton*[1]

Location	Percent of time found on specific location	
	Normal bract	Frego bract
Off plants	2	12
Leaves	7	19
Stems	12	15
Terminals	3	35
Squares	74	19
Flowers and bolls	2	0

[1] From W. H. Cross, Boll Weevil Research Laboratory.

TABLE 2.—*Behavior of female boll weevil on Frego and normal bract cotton*[1]

Activity and rate	Normal bract	Frego bract
Eggs/hour	0.97	0.50
Movement (feet/hour)	1.20	9.40
Feeding (minutes: seconds/ puncture)	3:45	5:24
Oviposition (minutes: seconds/ puncture)	0:41	1:22

[1] From W. H. Cross, Boll Weevil Research Laboratory.

TABLE 3.—*Summary of field experiments comparing normal bract and Frego bract cotton*

Year and experiment	No. of replications	Avg. eggs/ acre/week (1,000)		Reduction in Frego plots (%)	
		Frego	Normal	No. eggs	No. insecticide treatments
1970:					
A	1	3.0	8.8	66	([1])
B	1	9.3	32.1	71	([1])
C	1	.5	8.4	94	100
D	1	6.7	27.9	75	50
1971:					
E	3	.8	1.1	29	0
F	4	.9	3.1	69	53
G	4	1.2	5.8	79	62
1972:					
H	12	3.9	7.8	50	46

[1] Unknown.

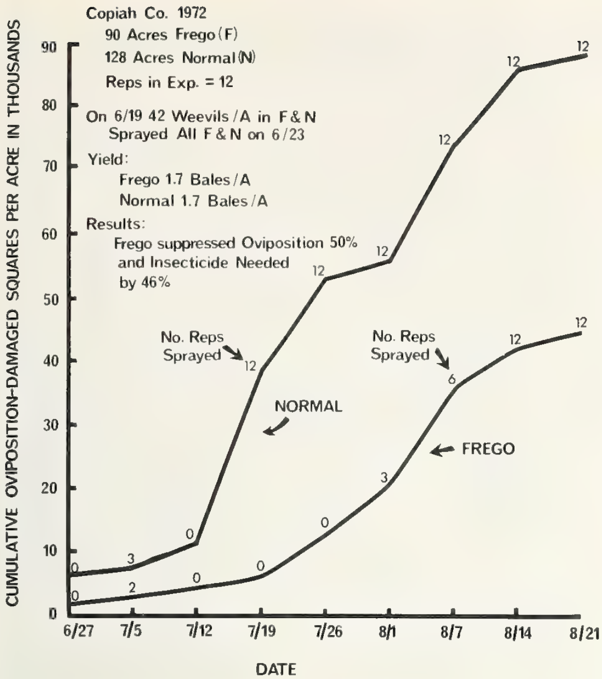

FIGURE 1.—Data from Copiah County experiment.

these two farms. We planted 90 acres of Frego bract and 128 acres of normal bract. We conducted bug-catcher (tractor mounted) sampling of each field for several weeks. On June 13 the cotton was beginning to have pinhead squares.

On June 19, we caught an average of 42 weevils per acre in each of the 12 Frego and 12 normal fields. Since we were on farmer fields being used for commercial production, this level of infestation called for an application of insecticide. Between June 20–23 one-fourth pound of methyl parathion was applied to each field. After this application, each of the 24 fields was sprayed only when the level of egg-damaged squares exceeded 10%. The overall results were a 50% reduction in oviposition-damaged squares per acre and 46% fewer applications of insecticide were used in the Frego than in normal bract. The yield was equal in the Frego bract and normal. One grower's yield was slightly less than the others, but equal for each type.

The detailed week-by-week population figures are shown in figure 1. Above each data point on the graph for Frego and normal are shown the number of fields (reps) of each cotton type out of 12 that required insecticide in a given week. In the Frego bract, after the initial application to all 12 fields on June 20, there were two fields on July 5, three fields on August 1, and six fields on August 7 that required insecticide. Beginning on August 14 all 12 fields were in need of boll weevil insecticides. The picture was quite different on the normal bract. After the initial application to all 12 fields on June 20, there were three fields that required insecticide on July 5, and on July 19 all 12 fields needed insecticide for boll weevils and continued to need applications each week throughout the season.

Under these conditions the total eggs per acre oviposited in Frego bract for the season was 44,000. For normal bract it was 88,000.

These data are typical of what one can expect from Frego bract as a boll weevil resistance character. In essence, in the 1972 experiment we did not develop economic levels of boll weevil until the August generation in the Frego bract. It is significant that Frego bract was effective early in the season, when it would be needed in an integrated program. One can easily see that if the Frego fields had received as many insecticide applications as the normal bract fields, the net results would have been an even more outstanding suppression of the population in the Frego bract.

In another study conducted with Frego bract, azinphosmethyl and methyl parathion applied at 0.125 lb/acre left greater deposits and caused higher mortality of boll weevils on Frego than on normal bract cotton squares under the following conditions: (1) When the cotton was sprayed in the field and weevils were immediately caged on the whole plants of the two types of cotton, (2) when weevils were placed in 1-pint cartons with squares removed from the two types of plants after spraying, and (3) when weevils were placed in cartons with squares from each cotton type, which were sprayed after they were removd from the plants. These results were confirmed by recovery of approximately seven times the amount of residue from Frego than from normal bract buds sprayed with methyl parathion. When both bracts and buds on each type of cotton were analyzed for residue, the results were about equal, but if buds only were considered, the Frego buds had about seven times more. This obviously reflects the protective nature of the normal bracts around the bud.

In several studies we and others have confirmed that Frego bract cotton is more sensitive to plant bug damage than normal bract cotton.

The cause for this has not been determined, but it is being worked on. This susceptibility can cause a delay in maturity and a reduction in yield if plant bugs are not controlled. Any time a delay in maturity or a reduction in yield of Frego bract is experienced, one should suspect that plant bugs were involved.

The following is some agronomic data comparing one strain of Frego, La–Frego–2, with commercial varieties. This strain is in a 'Stoneville 7A' background, and in 1972 was in the backcross 5 generation. The strain is being developed by J. E. Jones of the Agronomy Department at LSU. Our 1972 experiment in Copiah County was with this strain.

Table 4 shows agronomic and fiber properties of 'ST 7A', 'DPL–16', La–Frego–2, and La–Frego 3159 (an advanced Frego selection). The data are the average from three locations and four replications at each location. In earliness, La–Frego–2 is equivalent to 'ST 7A', and La–Frego 3159 is about equivalent to 'DPL–16'. The Frego lines have 1% less lint. Micronaire is comparable. Fiber length is 0.02 inch shorter. The fiber strength of La–Frego–2 is slightly less than that of commercial varieties; however, the 3159 selection is equal to the commercial varieties.

Table 5 shows lint yields from four replications and three locations each. At Baton Rouge, La–Frego–2 was superior to 'ST 7A' and slightly inferior to 'DPL–16', but the differences were not significant in either case. At Bossier City, La–Frego–2 was equal to 'ST 7A' and superior to 'DPL–16', but again neither difference was significant. At St. Joseph, La–Frego–2 yielded less, but not significantly so, than 'ST 7A' and 'DPL–16'. Thus, in 1972 at three locations with four replications each, there was no significant difference in lint yield of La–Frego–2 and 'DPL–16' or 'ST 7A'. Each of the three cottons yielded over two bales per acre.

Table 6 shows lint yields of the three cottons. These results are from three locations and are the average of 4 years and 4 replications each year at each location. At Baton Rouge, La–Frego–2 yielded 101 lb of lint per acre more than 'ST 7A' and 85 lb of lint per acre more than 'DPL–16'. At Bossier City, La–Frego–2 yielded 67 lb of lint per acre less than 'ST 7A' and 56 lb of lint per acre less than 'DPL–16'. At St. Joe, La–Frego–2 yielded 50 lb/acre more than 'ST 7A' and 37 lb/acre more than 'DPL–16'. The last column shows the average of 4 replications per location for 4 years and 3 locations for the 3 cottons. La–Frego–2 yielded 28 lb of lint per acre more than 'ST 7A' and 22 lb of lint per acre more than 'DPL–16'.

Overall, our data show a summary of the host-plant resistance potential of Frego bract as a

TABLE 4.—*Agronomic and fiber properties of normal bract commercial varieties and two experimental strains of Frego bract in 1972*

[Avg. of 3 locations, 4 replications each]

Variety or strain	First picking (%)	Lint (%)	Micronaire	2.5% span length (inches)	Strength (g/tex)
'St 7A'	77	39.7	5.0	1.16	21.2
'DPL–16'	82	39.4	4.7	1.16	22.1
La–Frego–2	76	38.6	5.0	1.14	20.8
La–Frego–3159	83	38.6	4.8	1.15	22.3

Source: J. E. Jones, LSU Agronomy Department report of projects, 1972.

TABLE 5.—*Lint yields of two normal bract commercial varieties and a Frego bract experimental strain in 1972*

[Avg. of 4 replications at each location]

Variety or strain	Pounds lint/acre[1]			
	Baton Rouge	Bossier City	St. Joseph	Avg.
'St 7A'	914a	1,114a	1,082a–c	1.037
'DPL–16'	1,072a–d	1,076a	1,089a–b	1,079
La–Frego–2	1,040a–d	1,112a	1,020a–d	1,057

[1] Means for each location followed by the same letter do not differ significantly at the 0.05 level.

Source: J. E. Jones, LSU Agronomy Department report of projects, 1972.

TABLE 6.—*Four-year average lint yields of two normal bract commercial varieties and one experimental strain of Frego bract grown at three locations with four replications per year*

Variety or strain	Pounds lint/acre			
	Baton Rouge	Bossier City	St. Joseph	Avg.
'St 7A'	763	953	980	899
'DPL–16'	779	942	993	905
La–Frego–2	864	886	1,030	927

Source: J. E. Jones, LSU Agronomy Department report of projects, 1972.

boll weevil resistance trait. The problem of increased sensitivity to plant bugs was pointed out. Frego bract's agronomic, fiber, and yield potential were shown. It seems to be a very worthwhile character.

We have been working on other characters for resistance to boll weevils also. We have tested 181 photoperiodic wild cotton lines for boll weevil resistance, and found 64 of these to be significantly more resistant than our commercial cotton varieties. The resistance was measured as eggs per female weevil caged on squares from these cotton lines. The average number of eggs per female on our check line (which was the strain M8) was 9.5. On the best resistant strain we obtained only 1.5 eggs per female per day. Several strains were in the range of three to five eggs per female per day. These strains are all photoperiodic and will not flower in the United States. We have worked with 22 of these in a breeding program and after two backcrosses to Upland, we now have good flowering types in all 22 lines. Field tests in 1973 in small replicated plots showed that three lines were carrying the combination of flowering type, i.e., day-neutral and boll weevil resistance. We are very encouraged by this. We believe we can also recover the boll weevil resistance in the other lines, now that we have plants that flower. Agronomic and fiber properties are also moving in the right direction in the lines. We are in the process of making F_1 crosses with the remainder of these 64 resistant lines with Upland varieties.

MASS REARING OF BOLL WEEVILS

By O. H. Lindig[1]

In less than two decades, the rearing of boll weevils has evolved from the laboratory rearing of a few insects per week on natural food to the production of millions per week.[2] These advances are the result of the work of many researchers, the most important being the development of an artificial diet in 1957 by Vanderzant and Davich (1958). The development of an artificial diet on which the boll weevil could be perpetuated not only started researchers to work on mass rearing, but also allowed nutritional studies to begin. Vanderzant (1959, 1961, 1964 and 1965) subsequently made many studies on lipid requirements, and on defined diets to establish amino acid, carbohydrate, and mineral, and vitamin requirements. There was other work in nutritional research, such as Earle's (1967) work on sterol requirements and (1967) essential fatty acid requirements. In addition to the specific nutritional requirements of the boll weevil, others were working on modifications of diet, including Sterling (1966), Earle (1966), and Gast (1966).

Gast (1963) realized that in order to mass-rear the boll weevil, not only was an efficient and economical diet necessary, but mechanical devices were also required. Much of his work was on improving the procedures for egg extraction, implanting eggs on larval diet, and preparation of oviposition diets. He also designed improved cages for holding the adults and developed a method for collecting emerging adults. Many of his developments, some with modifications, are still in use today, and all are adequate for production levels of 100,000 adults per week or less. Major changes in procedures and priorities were indicated, however, when the demands for boll weevils became millions per week. For an example, when only 10 to 20 gal of diet a day are required, autoclaving is an effective and efficient method of diet sterilization, but when daily requirements are several hundred or several thousand gallons, autoclaving is impractical, if not impossible. The same holds true in the forming and wax-coating of the oviposition diet. The implementation of flash sterilizers and pellet-forming machines (Griffin 1973) solved most of these problems. Today, the quantity of diet sterilized and oviposition pellets produced is limited only by the size and number of machines one wants to operate.

The cost of the diets, fecundity, hatch, yield of adults from eggs, yield of adults per given volume of diet, and other factors which are of minor importance in small cultures become exceedingly important as production increases to the millions per week level. This can be illustrated by considering the requirements at a production level of 200 million adults per week. For this level, weekly requirements would involve supplying 30,000 gal of larval diet, inoculating 1.5 billion eggs, and supplying 20 million females (40 million mixed sex) 14,000 gal of diet in which to oviposit. It is apparent that a minor reduction in the cost of diet, a small increase in adult yield, would be important. Most of our research has been directed toward these last areas and toward mechanization of procedures.

The oviposition diet now in use (Lindig 1972) can be prepared, excluding wax coating, for approximately 88¢/gal. The larval diet presently costs \$1.22/gal, but a new larval diet, costing about \$1.14/gal, is currently being tested. The new larval diet is also being tested as an oviposition diet in hopes that a single diet can be utilized, and preliminary results show it to be equal or slightly better than the standard ovi-

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[2] In 1973, the Robert T. Gast Rearing Laboratory at Mississippi State, opened in May 1972, produced 2.7 million sterile males. It was used to produce the sterile males released in the Pilot Boll Weevil Eradication Experiment.

position diet in total egg production and hatchability. Females also produce eggs for a longer period of time when fed this diet, which reduces the percentage of each generation which must be returned to the colony. All of these factors contribute to cost reduction of mass-reared weevils. Different environmental conditions during larval development are also being studied, and a preliminary test indicated that yields of adults, the number of eggs and volume of diet being equal, could be increased twofold over the standard environmental conditions of 29° C and 50% relative humidity.

Research in mechanization of procedures has resulted in the utilization of flash sterilizers (Griffin et al. 1974) for sterilizing the diets. The characteristics of these units make them adaptable to the mechanization of other procedures, such as the forming of oviposition pellets. Studies are now underway to simplify and mechanize the handling of the larval diet and egg implantation, as well as to replace the petri dish with a less expensive container.

One of the major problems associated with mass rearing is contamination of the diets, which results in a lowered production of eggs and adults, higher costs, and a weevil of lower quality. More importantly, this problem makes it impossible to predict production levels. In addition to microbial contamination, Gast (1966) reported a protozoan disease *Glugea gasti*, that destroyed his colony at the Boll Weevil Research Laboratory. Childress (1973) reported that erythromycin effectively controlled a bacterium that appeared to be common to many types of insect cultures.

Because of the cost of the inhibitors, their detrimental effect at higher concentrations to the developing larvae, and the potential risks to workers who handle antibiotics, it is highly desirable that the use of these materials be kept at a minimum. The effective management and supervision of workers, strict adherence to sanitary procedures, and the proper training and motivation of all employees will substantially reduce contamination problems. Regardless of the technological advances made in nutrition, mechanization, or contamination control, the ultimate success of failure of a mass-rearing program depends upon the skills and dedication of the people involved.

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BOLL WEEVIL STERILITY

By T. B. Davich[1]

Table 1 is a brief summary of some of the results of the first boll weevil sterilizing experiment ever conducted (Davich and Lindquist 1962). The weevils were sterilized by exposure to gamma rays in a cobalt^{60} source. As the table shows, the gamma-ray dose necessary for male sterility is also the lethal dose. Subsequent studies by a number of investigators generally confirmed these original findings. Fractionated doses of gamma rays were tried and were ruled out (Flint et al. 1966), although recent research indicates that very low doses and extension of the time interval between exposures may have some merit. Thermal neutrons, fast neutrons, and microwaves were tried by several investigators (Klassen et al. 1969). They resulted in sterility, or partial sterility, but at the cost of high, early mortality. Detailed laboratory studies indicated that even with the high, rapid mortality the gamma-ray-sterilized weevils might be able to suppress a low-level population. These laboratory studies indicated that the sterilized males could be relatively competitive for 4 to 5 days following irradiation (Bartlett 1968). To test the principle we ran a field test in West Texas in 1968 on 65 acres of cotton.[2]

Releases of sterilized weevils were made, by hand, twice weekly beginning June 4 and ending September 14, for a total of 30 releases. Mortality counts made at the time of release averaged 8.5%. Over a million sterilized weevils, or approximately 15,750 per acre, were released during the 15 weeks. Extensive manual and machine sampling indicated that we were holding, even depressing, the native population. There were 50 field examinations during the course of the experiment.

Table 2 shows the number of native weevils captured during the experiment. From July 8 to August 26, 19 manual surveys failed to uncover a single native weevil. These manual surveys ranged in size from 275 to 10,000 lin ft. The tractor-mounted mechanical sampler (bugcatcher) failed to pick up a single native weevil in five surveys from July 18 to August 1. Then, beginning August 28, a general migration occurred in the area, and the manual surveys started to pick up significant numbers of weevils.

Table 3 shows the results of square dissections. Squares containing larvae were counted both as eggs and hatched eggs. Again, it appears that the released steriles were exerting a depressing effect on the native population until migration occurred beginning during approximately the second week in August and reaching epidemic proportions in late August.

In Plaquemines Parish, La., about 60 mi south of New Orleans, we conducted in 1962 the first field test (Davich et al. 1965) of the sterile-male technique on the boll weevil. The 6-acre test field was 30 mi south of the 1-acre check field. These 2 fields were about 50 mi from the nearest commercial cotton. We released 10 gravid females in each field. In the test field, all 10 females were released in a 1-acre portion of the field. In the next 5 days we searched for the released females. Eight established themselves very near each release site; one moved 17 rows and the other 77 rows from the release site. Our method of detection consisted of looking at every square in the field for oviposition punctures. Detection of very low-level populations is an important problem now as it was then. Because squares were plentiful, the released females moved very little after establishing themselves. The number and timing of the sterile-male relases were based on certain theoretical calculations involving the number of F_1 offspring that we might expect, the develop-

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[2] O. H. Lindig and T. B. Davich. Unpublished data.

TABLE 1.—*Boll weevil adult mortality and hatch of eggs obtained following the mating of irradiated males with normal females*

Dose (K rad)	Days to— 50% mortality	90% mortality	Egg hatch (%)
0	30.0+	....	97
5	8.0	11.0	32
10	7.0	10.0	9
15	6.5	8.5	0

mental period, peak emergence, and other factors. We decided to strive for a constant 20:1 ratio of released sterile males to normal males developing in the field. The males were sterilized by dipping them twice, at an interval of 24 h, for 15 s in a 2% apholate solution. They were released once each week. To offset the mortality that would follow handling, shipping, and toxicity of the chemosterilant, we dipped approximately twice the number of males we actually released. We prevented reproduction of the population of boll weevils in this test (table 4). De-

TABLE 2.—*Native weevils captured on 65 acres in boll weevil sterile-release test in West Texas, 1968*

Date	Native weevils/acre	Percent of field sampled	Sampling method
June 27	1.05	1.4	Survey.
July 3	.90	1.7	Do.
July 8	.20	7.9	Bugcatcher.
July 11	.20	7.8	Do.
July 18–Aug. 26[1]	0	0.25–1.0	Survey.
July 18–Aug. 1[2]	0	6.5–8.8	Bugcatcher.
Aug. 5	.17	9.0	Do.
Aug. 22, Aug. 26	0	[3]9.0	Do.
Aug. 28	23	.14	Survey.
Sept. 4	91	.02	Do.
Sept. 12	454	.02	Do.

[1] 19 samplings.
[2] 5 samplings.
[3] Mean value.

TABLE 3.—*Results of square dissections in 1968 West Texas sterile boll weevil release experiment*

Dissection date	No. larvae plus viable eggs/acre	No. eggs in sample: Total	No. hatched
July 8–July 15[1]	0	16	0
July 16–July 18[2]	7–90	127	7
July 22–July 24	0	40	0
July 25	26	4	2
July 26	0	1	0
July 29	21	11	1
July 31–Aug. 1[2]	0	16	0
Aug. 5	32	11	1
Aug. 7–Aug. 19[3]	14–63	79	6
Aug. 26	150	28	6
Aug. 29	220	36	20

[1] 5 samplings.
[2] 3 samplings.
[3] 4 samplings.

TABLE 4.—*Oviposition punctures and egg hatch in an experimental effort to eradicate an artificial infestation of the boll weevil in plots in Louisiana*

Observation date	Test plot[1]: Squares with oviposition punctures at release site[2] No.	Percent	Hatch of eggs dissected from square[3] (%)	Check plot[1]: Squares with oviposition punctures at release site[2] No.	Percent	Hatch of eggs dissected from square[3] (%)
Aug. 1–2	112	....	..	9	....	...
7–8	181	11.0	..	10	....	...
15	79	15.8	0	....	....	70
20–21	160	6.4	0	56	....	86
28–29	182	36.5	0	....	5.5	100
Sept. 5	84	14.0	0	....	....	70
8	11	11.0	0	....	....	...
12	[4]289	9.0	0	....	....	...
19	[4]131	6.3	0	[5]1,502	34.8	...
24	3	.9	0	....	....	...
Oct. 10	3	1.0	0	1,031	40.0	...
22	...	....	..	....	17.0	...
Nov. 15	[6]0	0	..	138	41.0	...
21	[6]0	0	..	[5]1,070	37.8	...

[1] 10 gravid females placed in the test plot on July 26. 5 gravid females placed in the check plot on July 26 and again on August 14. Check plot sprayed October 10 and 22.
[2] Release site consisted of a circle having a 25-ft radius centered on the female release plant or establishment point.
[3] From 6 to 100 squares dissected each week.
[4] All squares examined in 5 randomly selected 100-ft row sections in the release acre.
[5] Randomly picked squares.
[6] Squares on every plant in field examined.

tails of other calculations, based on the observed number of eggs laid by the original 10 gravid females, indicated that we actually had a ratio of no less than 47:1 of sterile: normal males. At the termination of the experiment, the 1-acre check field had a population of 74,000 boll weevils. Egg hatch in the check ranged from 70% to 100%.

Our most ambitious field experiment up to 1968, when we did the West Texas experiment, was an attempt to eradicate a natural field population of weevils in a partially isolated area of the Cotton Belt in 1964 (Davich et al. 1967). The males were sterilized by two 15 s dips, 24 h apart, in a 2% apholate solution. Figure 1 shows the experimental setup in Baldwin County, east of Mobile, Ala., where we attempted to eradicate the boll weevil with a combination of applications of insecticides and sterile-male releases. The number of letters in each circle indicates the number of fields at that location. All the circled fields below a line running from Robertsdale west were treated eight times with methyl parathion at weekly intervals in the autumn of 1963 to reduce the overwintered population to as low

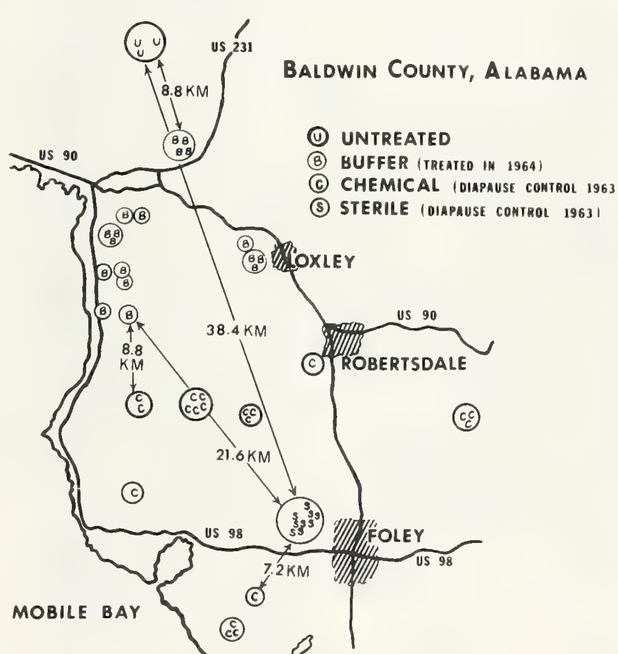

FIGURE 1.—Experimental setup of insecticide plus sterile-release boll weevile experiment, Baldwin County, Ala., 1963, 1964.

a level as possible. The weevil population was estimated to be about 30 per acre on each of five weekly counts towards the end of the treatment period. No hibernating weevils in the treated zone, and 160 per acre in the untreated buffer zone were found in the examination of limited numbers of spring woods trash samples. Five boll weevils were found in 1964 on 11,500 lin ft of seedling cotton inspected in the buffer zone. None were found on 13,000 lin ft of seedling cotton inspected in the chemical control zone.

Table 5 shows the oviposition-punctured square counts for two of the three fields treated with insecticides interspersed with the release of sterile males. Field 1 was the best and field 3 the worst. Field 4 was the best of the six fields which received sterile males only, and field 5 was the worst. In no case was the economic damage threshold reached.

We did not achieve eradication for the following reasons: (1) Lack of isolation, (2) too high population levels to start with, (3) quality control data on the released males indicated that sterility ranged from 100% down to 88%, with a mean of 95.8%, (4) males that survive for 3 to 4 weeks regain a high degree of fertility, and (5) sexing errors resulting in the release of up to 2% females, against which apholate is a poor sterilizing agent.

We surveyed the area in 1965 to follow the population buildup. Table 6 shows the results. We did nothing to suppress the populations in any of the areas in 1965. It is evident that there was a definite carryover effect in the sterile-release area.

In cooperation with Auburn University sterile boll weevil release experiments were conducted in the Coosa River Valley of east-central Alabama in 1970–71.[3] In 1971, the release fields were located 5 mi south of Talladega and were bordered on two sides by the Talladega National Forest. The test fields were included in the Coosa River diapause program of 1970. There were eight release fields totaling 125 acres. Two fields, 26 and 4 acres, received males; two other fields, 30 and 5 acres, received females; and four other fields, 10, 30, 10, and 10 acres, received both sexes. The release fields were trapped from May 7 to July 2, using grandlure-baited traps at a rate of approximately one per acre. We trapped from 9.6 to 26.9 weevils per acre around the fields, which is too high a level for the use of the sterile-male technique. However, we proceeded to make the weekly releases as planned.

Sterile releases were made weekly from July 7 to August 18. The weevils were released at a rate of approximately 278 per acre in the male fields, and 270 per acre in the female fields. In the mixed-sex fields, the weevils were released at a rate of 225 per acre. As table 7 shows, there appeared to be little difference in the suppression obtained among males, females, or mixed sex. Why females only suppressed the populations, we can only speculate.

The research program originally took two approaches to sterilize the boll wevil. First, sterilization by gamma rays and second, sterilization through the use of chemicals. Each has its advantages. The first, radiation, is a relatively quick procedure and can be accomplished with little handling. Also, with radiation both sexes are sterilized. Chemosterilization, on the other hand, obviates the necessity for the expensive, sophisticated irradiation equipment. The method we finally chose, chemosterilization, was based on its overall effectiveness and ability to supply apparently vigorous weevils of sufficient longevity to fit our needs—something which we have been unable to accomplish using radiation.

Apholate, an alkylating agent that had shown some effectiveness with houseflies, was also effective to a high degree with the weevil (Hedin et al. 1964, Lindquist et al. 1964). It can be sprayed on cotton plants or fed to reared adults in media. However, it is quite toxic to the weevil, resulting in 50% to 60% mortality in 48 h. Further, an appreciable percentage of the males recover fertility if they live long enough. Hempa (Haynes et al. 1966) was found to be an effective sterilant when the weevils were fed on medicated diet, but they recover their fertility if they subsequently feed on squares. Dipping the males in hempa failed to induce sterility (Haynes et al. 1966).

In 1966 we contracted the Southern Research Institute at Birmingham, Ala., to conduct an extensive screening program for new promising chemosterilants. During a period of 4 years they screened well over 3,000 candidate materials, some of which we are still following up to this day. Additionally, we had extensive cooperation

[3] Floyd R. Gilliland, principal investigator. Data unpublished.

TABLE 5.—*Oviposition-punctured squares in selected fields in Baldwin County, Ala., boll weevil sterile-relase experiment, 1964*

Field No.	No. insecticide applications	No. punctured squares/acre (seasonal) Low	High	Mean
1	5	24	353	118
3	4	54	1,836	1,055
4	0	0	60	27
5	0	0	788	169

TABLE 6.—*Boll weevil population building in 1965 following termination in 1964 of Baldwin County, Ala., sterile-release experiment*

Type record	Date	Weevils/acre in zone		
		Buffer	Chemical	Sterile
Woods trash	March	194	0	0
Trap crop[1]	May	24	6	1
On field plants and				
in shed fruit	June 15	436	45	0
Do	June 30	409	435	17
Do	July 28	7,194	2,004	1,386

[1] Total weevils captured, not weevils per acre.

from Agricultural Research Service laboratories in Fargo, N. Dak., Florence, Ala., and Baton Rouge, La.

A number of promising leads came out of this cooperative program, and busulfan, the chemosterilant of choice at present, was found (Klassen and Earle 1970). They found that prolonged feeding of this material could cause male sterility in excess of 95%. Busulfan, if manipulated properly, can and will sterilize males without causing undue damage to either the vigor or libido of the weevils. It has two disadvantages: (1) It does not sterilize a high enough percentage of the females, which means that we have to separate the sexes, and (2) there is very little margin of error in the required concentration. In other words, the sterile dose and the lethal dose are quite close.

TABLE 7.—*Summary of results of sterile release test in Coosa River Valley, Ala., 1971*

Sex released	Mean squares with viable eggs and larvae (%) July 21	Aug. 3	Aug. 26	Avg.
Female	0.8	2.5	27.8	15.4
Male	.5	1.2	42.0	14.0
Both	1.8	3.6	32.8	15.4
Control	33.0	54.0	82.0	45.0

A combination of busulfan and hempa appears to be superior to busulfan alone (Haynes et al. 1972). In any case, as we have noted on many occasions, we still need better chemosterilants and more efficient ways of administering them. In the interest of economy, we need to reduce the time necessary to sterilize the weevils. We need sterilants which will allow us some margin of operating error, so that we can get off the razor's edge we teeter on with our present materials. We need sterilants with which we can determine the dosages, rather than leaving it to the weevils' whim, as is the case when it feeds on a medicated medium. To that end a number of cooperating laboratories are examining other methods of application, particularly fumigation with various promising materials—radioactive gases, modifications of radiation procedures, and combinations of such procedures. We are optimistic that we will succeed in developing a method of sterilizing both sexes without undue impairment of mating competitiveness.

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EVENTS LEADING TO THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By C. R. Parencia, Jr.[1]

The boll weevil, *Anthonomus grandis* Boheman, was described in 1843 by C. H. Boheman from specimens received from Vera Cruz, Mexico. The first report of the occurrence of the boll weevil in the United States was received by the Department of Agriculture in the fall of 1894 from Brownsville, Tex. The result was that C. H. T. Townsend of the Division of Entomology was sent to Texas. He found that several counties were infested with boll weevils and that serious damage had been caused by the pest since 1892. It is not the purpose of this discussion to give the history of the spread of the boll weevil in this country, but comments relating to early research seem to be in order.

Townsend's report relating to the area infested and the life history and habits of the boll weevil was published in March 1895 in Insect Life, Vol. 7, No. 4. He recommended in his report that cotton stalks be destroyed to kill overwintering weevils and that a noncotton zone be established to prevent further spread of the pest insect. The Department of Agriculture reported the seriousness of the pest to the Governor of Texas and urged immediate legislation to permit quarantines and remedial work. By 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Tex., and 1898 was an especially bad year for boll weevils. The Legislature of Texas therefore made an appropriation for research and appointed a State entomologist to investigate means of control. The work on the boll weevil by the Division of Entomology of the Department of Agriculture was therefore discontinued at the end of that season.

Nevertheless, the boll weevil continued to spread, and it was not long, 1901, before other States were threatened with invasion. Congress therefore made a special appropriation to support research designed to discover a means of preventing further spread. The resulting program was directed by W. D. Hunter. In 1908, Hunter demonstrated the cultural methods of controlling the boll weevil that had been developed by and were recommended by the Division of Entomology on eight cooperating farms. These farm demonstrations developed into the Farmers' Cooperative Demonstrations of the Bureau of Plant Industry and later into the present Extension Service of the Department of Agriculture.

A laboratory was established at Victoria, Tex., in 1902. This work was moved to Dallas, Tex., in 1905 and from Dallas to Tallulah, La., in 1909. There it remained until June 30, 1973.

The development of materials capable of controlling the boll weevil is of considerable interest, but time does not permit more than a brief discussion here. Paris green was tested in 1896, but it was not an effective material. In 1908, lead arsenate was formulated as a dust and at first seemed a promising supplement to cultural methods of controlling the boll weevil. However, results were erratic, and the method was not recommended by the Bureau nor used extensively by growers.

The first breakthrough came when the then new insecticide, calcium arsenate, was used in field tests against the boll weevil in 1916. Although problems with formulation were encountered, sufficient progress had been made by 1921 so that the material was tested in several sections of the Cotton Belt by Tallulah laboratory personnel. Machines for applying the material were developed at the same time. The story of the development of calcium arsenate for control of the boll weevil is worthy of treatment elsewhere than in this discussion.

The next step in boll weevil control was the application of calcium arsenate dust from airplanes. The use of airplanes was suggested by the success of the Ohio Agricultural Experiment Station achieved with aerial applications of lead arsenate for control of the catalpa sphinx, *Ceratomia catalpae* (Boisduval), in 1921. However, the first such efforts against cotton insects were made against the cotton leafworm, *Alabama argillacea* (Hübner), in 1922. Thereafter, this method of application rapidly became wide-

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spread, and commercial companies soon maintained fleets of airplanes for use in controlling the boll weevil and the cotton leafworm.

Calcium arsenate dust and its application via aircraft was a major breakthrough in boll weevil control, but the insecticide was never widely accepted because its use often caused the development of infestations of the cotton aphid, *Aphis gossypii* (Glover). This pest, if uncontrolled, would cause damage sufficient to offset any benefits obtained by controlling the boll weevil. Nicotine sulfate was developed as an aphicide, but it was difficult and unpleasant to formulate and apply, and it never gained wide acceptance.

The next major breakthrough was the development of organochlorine insecticides. However, the first of them, DDT, did not control the boll weevil. Only when BHC, toxaphene, aldrin, dieldrin, and heptachlor were developed did growers have more efficient insecticides than calcium arsenate. When these effective materials were mixed with DDT, the mixture controlled both the bollworm, *Heliothis zea* (Boddie), and the boll weevil; and parathion could be used as an aphicide when needed. Thus, once low-pressure, low-volume sprays had been developed, growers and researchers felt that the situation was well in hand.

Unfortunately, the era of control with organochlorine insecticides was short-lived. By the mid-1950's the boll weevil had developed resistance. However, in the meantime, methyl parathion, and later azinphosmethyl, were developed for control of the boll weevil.

The threat of resistance now created an era of apprehension. Spokesmen for the cotton producers repeatedly emphasized that the survival of the industry depended on adequate research designed to strengthen the ability of U.S. producers to compete for markets. Leading scientists and spokesmen for industry agreed that the presence of the boll weevil in cotton-producing areas posed a major and costly problem for the cotton industry and that research support was an urgent need. As a result, in the Agricultural Appropriation Reports for fiscal year 1959, both the House and Senate Agriculture Committees requested the Secretary of Agriculture to review the boll weevil problem and to submit a report on research and facility needs.

A working group was subsequently appointed by the Office of the Secretary to (1) develop information about current research programs devoted to the boll weevil by State and Federal Governments and by private industry, (2) determine the needs for an overall comprehensive program, and (3) determine the broad area of research that would be appropriate for Federal attention and support. This group consisted of H. G. Johnston of the National Cotton Council of America, E. R. McGovran of the Cooperative State Research Service (CSRS), and E. F. Knipling (chairman) and C. R. Parencia (secretary) of the Agricultural Research Service (ARS). The information requested by Congress was obtained by visiting various Divisions in ARS, by talking with the Agricultural Experiment Stations in the major cotton-producing States infested with the boll weevil, and by conferring with the various sectors of private industry. The report was submitted December 30, 1958. Funds were thereafter appropriated by Congress for the establishment of the Boll Weevil Research Laboratory (BWRL) on the campus of Mississippi State University and for the strengthening of ongoing research at the ARS Cotton Insect Research laboratories at College Station, Tex.; Baton Rouge, La.; and Florence, S.C. The new facility at Mississippi State was dedicated in a formal ceremony in March 1962. The ultimate goal of the work projected there was the eradication of the boll weevil. Simultaneously, research involving the boll weevil was strengthened in several of the State Agricultural Experiment Stations.

As time passed, the expedited research produced the following significant findings: (1) Development of techniques for mass rearing the boll weevil, (2) development of the reproduction-diapause boll weevil suppression program, (3) development of the use of ultra-low-volume sprays of insecticides, (4) development of the systemic insecticide, aldicarb, that controls the boll weevil, (5) identification and synthesis of the attractant, grandlure, and design of traps that could be baited with the substance and used to capture boll weevils, (6) progress in developing a chemosterilant that could be used to produce sterile males for release, and (7) progress in the development of a Frego bract strain of cotton that has considerable resistance to the boll weevil.

The progress made and the importance and urgency of eliminating the boll weevil problem as soon as it became technically and operationally feasible resulted in the establishment of a special study committee on boll weevil elimination by the National Cotton Council of America at its 1969 annual meeting. The committee met in Memphis, Tenn., on May 6, 1969, to review current information concerning the status of boll weevil suppression measures and to consider what actions should be taken toward eliminating of the boll weevil as a pest of cotton. The chairman of the Special Study Committee, R. R. Coker, also appointed a subcommittee that was to select sites in the southeast, midsouth, and southwest regions of the Cotton Belt that would be suitable for areawide experiments to determine whether the elimination of boll weevils was feasible with currently available techniques.

The members of the subcommittee were J. R. Brazzel of the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture, H. G. Johnston of the National Cotton Council of America, David F. Young of Mississippi State University, C. R. Parencia of ARS, (secretary), and E. F. Knipling of ARS (chairman). The subcommittee met with appropriate administrators, with research, extension, and regulatory personnel, and with representatives of the cotton industry in South Carolina, Georgia, Alabama, Mississippi, Louisiana, Arkansas, and Texas to discuss the objective of the experiment and to outline the general procedures that would be used. In every conference, the representatives of the States agreed that a Pilot Boll Weevil Eradication Experiment (PBWEE) should be undertaken because of the urgency of an acceptable and permanent solution to this problem.

The report of the subcommittee entitled "Selections of Locations for Pilot Boll Weevil Eradication Experiments" dated August 15, 1969, was presented to the Special Study Committee on Boll Weevil Elimination in Memphis, Tennessee, on September 16, 1969. It recommended that a PBWEE be conducted in calendar year 1970 in an area centered in south Mississippi, but including adjacent cotton acreages in Alabama and Louisiana.

After the Special Study Committee accepted the recommendation of the subcommittee, it met with officials of the Department of Agriculture to discuss ways of financing the proposed experiment. One million dollars was available from ARS (later ARS and APHIS), $500,000 from CSRS, and $500,000 from industry, that is, from Cotton Incorporated. Mississippi would provide a facility for rearing boll weevils that would be sterilized and released. A detailed study of the area increased the estimated cost to $2.5 million, and the experiment was thus delayed until the additional financing could be obtained. However, in 1971, considerable reduction in the cotton acreage in the test area made it feasible to start the experiment with available funds.

The membership of the Technical Guidance Committee for PBWEE, appointed by the Office of the Secretary of Agriculture, consisted of P. L. Adkisson of Texas A&M University, F. S. Arant of Auburn University, Richard Carlton of the Louisiana Department of Agriculture, T. B. Davich of the BWRL, C. C. Fancher of the Mississippi Department of Agriculture, O. T. Guice of the Mississippi State Plant Board, F. G. Maxwell of Mississippi State University, R. C. Riley of CSRS, W. F. Helms of APHIS, J. S. Roussel of Louisiana State University, W. A. Ruffin of the Alabama Department of Agriculture, D. R. Shepherd of APHIS, George Slater of Cotton Incorporated, Ritchie Smith of the National Cotton Council of America, David Young of Mississippi State University, C. R. Parencia of ARS (secretary), J. R. Brazzel of APHIS (cochairman), and E. F. Knipling of ARS (cochairman).

The experiment got under way in July 1971 and was completed early in August 1973. The Technical Guidance Committee met August 30, 1973, to study the results. It concluded that it is "technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that are ecologically acceptable."

Subsequently, the Technical Committee to Develop Overall Plan for Boll Weevil Elimination was appointed by the National Cotton Council's Study Committee on Boll Weevil Elimination. This committee developed a plan and presented it to the Study Committee on December 3, 1973. The plan was submitted to the Secretary of Agriculture on December 12.

OPERATIONAL PLAN AND EXECUTION OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By F. J. Boyd[1]

The Pilot Boll Weevil Eradication Experiment (PBWEE) was conducted in an area which covered all or parts of 30 counties in south Mississippi, 5 parishes in Louisiana, and 2 counties in Alabama (fig. 1). It was necessary that the experiment be conducted in an area where the boll weevil was well established, populations consistently high, and execution of control measures difficult. Most fields were small, surrounded by high trees, and difficult to treat by aircraft. During the course of the experiment, field size averaged approximately 8 to 12 acres. This area was selected as being representative of the worst boll weevil conditions likely to be encountered in the boll weevil belt. Everyone concerned felt that if we could demonstrate elimination of the boll weevil from this area, we could successfully execute this program in any part of the boll weevil infested area of the United States.

The experiment was organized geographically with an eradication zone located in the center of a series of suppression areas (fig. 1). The eradication zone consisted of an area within a 25 mi radius of Columbia, Miss. Concentric buffer zones of approximately 50 mi in depth were established around the eradication zone. The actual evaluation of the test was done in the eradication zone. The buffer zones were designed to prevent or reduce migration of boll weevils into the eradication zone. A test area of this size was necessary since it had been reported that the boll weevil could migrate up to 45 mi.[2] Table 1 gives the number or cotton acres planted in the different zones in 1971, 1972, and 1973.

Execution of the operational phase of the experiment was carried out by a special team of entomologists and inspectors in the Methods Development Group of Plant Protection and Quarantine, Animal and Plant Health Inspection Service (APHIS) in cooperation with the other agencies involved in the implementation of the experiment.

For coordination and operational purposes, the area was divided into work units. One professional employee (unit supervisor) was in charge of and responsible for all operational activities conducted in his unit. These activities included locating and mapping all cottonfields, collecting infestation data, directing all contractual aircraft insecticide applications, and applying all other suppression measures prescribed in the experiment. A zone supervisor coordinated the activities carried out in each zone, which consisted of several work units.

SUPPRESSION MEASURES

The eradication plan developed for us in the PBWEE involved the integrated use of several suppression techniques, which included the use of chemical, biological, and cultural control methods. The suppression techniques were executed intensively in the eradication and first buffer zones. In the second and third buffer zones, they were executed less intensively, since these areas were designed to lessen the likelihood of boll weevil migration into the eradication zone.

The eradication scheme utilized eight techniques which were designed to progressively reduce the boll weevil population to achieve elimination. These techniques were (1) in-sea-

[1] Entomologist, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Prentiss, Miss. 39474.

[2] Davich, T. B., Hardee, D. D., and Alcala, M. J. 1970. Long-range dispersal of boll weevils determined with wing traps baited with males. J. Econ. Entomol. 63: 1706–1708.

FIGURE 1.—Pilot Boll Weevil Eradication Experiment area, with breakdown of interior areas and zones.

son control, (2) reproduction-diapause control, (3) cultural control—defoliation, (4) cultural control—stalk destruction, (5) pheromone traps, (6) trap crops, (7) pinhead square treatment, and (8) sterile-male releases.

EXECUTION

1971

In-season control.—The in-season boll weevil control phase was implemented primarily through the Cooperative Extension Services of the States involved. Producer meetings, newsletters, and radio programs promoted the need for good in-season insect control, kept producers informed on the boll weevil population level in each individual field and made recommendations concerning insecticides and methods of application. The PBWEE field personnel, through individual contact, encouraged producers to carry out a good in-season control program using the Cooperative Extension Service recommendations.

Although much effort was put forth to get producers to carry out on an adequate in-season control program, the results were not very successful. It was estimated by the Cooperative Extension Service that approximately 50% of the acreage received no in-season insecticide treatments. This was primarily because many of the growers had only a small acreage of cotton, and could not afford the type of application equipment necessary for an adequate insect control program. Furthermore, the availability of custom pesticide applicators was limited.

TABLE 1.—*Cotton acreage in the different zones of the Pilot Boll Weevil Eradication Experiment during 1971, 1972, and 1973*

Zone	No. of acres		
	1971	1972	1973
Eradication	3,222	2,906	1,817
1st buffer	3,829	3,905	4,894
2d buffer	4,774	3,041	[1]2,226
3d buffer	11,912	9,449	[1]9,967
Total	23,737	19,301	18,904

[1] Approximate acreage as estimated by the Cooperative Extension Service, Mississippi State University.

Reproduction-diapause control.—Fall insecticide treatments were applied at 5 to 12 day intervals beginning in August and continuing until frost to suppress late-season boll weevil reproduction and prevent weevils from attaining diapause. Helicopters were used to apply the treatments in the eradication and first buffer zones and fixed-wing aircraft were used in the outer buffer zones. In 1971 these treatments were initiated August 9 in the eradication and first buffer zones, and on approximately September 1 in the outer buffer zones. The treatments were applied at 5-day intervals in August, at 5- to 7-day intervals from September 1–15, at 7- to 10-day intervals from September 15–30, and at 10- to 12-day intervals after October 1. Malathion was applied as an ultra-low-volume spray at the rate of 1.2 lb/acre. In the whole treatment period, a total of 13 applications were applied in the eradication and first buffer zones, 8 applications in the second buffer zone, and 4 applications in the third buffer zone. A small number of fields in the third buffer zone, which had excessive weevil populations, received a fifth application. Table 2 gives the application dates for each zone.

Cultural control—defoliation and stalk destruction.—All cotton in the eradication and first buffer zones was defoliated when it reached the recommended rate of maturity (60% open bolls and other bolls at least 25 days old). The defoliant Def or Folex was applied at 1.5 pt/acre with water in a total mix of 5 gal/acre. The purpose of the defoliation was to reduce the weevils' food sources and speed up harvest operations. Also the removal of the foliage made any weevils remaining on the cotton more vulnerable to contact with the insecticide applied for diapause control. In 1971, 83% of the 7,051 acres was defoliated from October 1 to 15 and the remaining acreage was done from October 20 to 27.

Cotton stalks were destroyed in all eradication and first buffer-zone fields harvested prior to the first killing frost, thus completely eliminating all boll weevil food and breeding sites in these fields. But with a reasonably wet fall in 1971, harvest was slow, and only 2,724 acres was destroyed prior to the first frost on November 11.

1972

Pheromone traps.—Boll weevil pheromone traps were used around eradication and first buffer-zone fields in the spring and summer to capture overwintered boll weevils as they em-

TABLE 2.—*Inclusive application dates of reproduction-diapause boll weevil control treatments applied in the Pilot Boll Weevil Eradication Experiment area in 1971*

Application No.	Zone			
	Eradication	1st buffer	2d buffer	3d buffer
1	Aug. 9–16	Aug. 9–15	Aug. 30–Sept. 7	Aug. 30–Sept. 7
2	14–18	14–18	6– 9	Sept. 13–21
3	19–25	19–25	13–15	27–30
4	24–28	24–28	20–22	Oct. 12–14
5	Aug. 30–Sept. 5	Aug. 30–Sept. 4	28–30	....
6	Sept. 7– 9	Sept. 6– 8	Oct. 7– 8	....
7	13–18	13–15	18–21	....
8	21–22	21–24	29–30	....
9	27–30	27–30	....	....
10	Oct. 7– 9	Oct. 7– 9	....	....
11	18–20	18–20	....	....
12	28–29	28–29	....	....
13	Nov. 9–10	Nov. 9–10	....	....

erged from hibernation quarters and to pinpoint high boll weevil survival areas. The traps were located around the fields next to potential boll weevil hibernation sites. Both fields that were planted to cotton the current year and unplanted fields that had been planted the previous year were trapped at an approximate rate of two traps per acre from mid-April until mid-July. The traps were baited with the synthetic pheromone, grandlure, either once or twice per week, depending upon the formulation being used. Two traps per field remained in service throughout the fall and winter to monitor boll weevil movement and population levels. Two traps per acre were also in service for 2 to 3 weeks at the time of stalk destruction in each field. Table 3 gives the average number of traps in service per week during each month.

Trap crops.—A four-row strip of trap-crop cotton extending the length of the field was planted in every cotton field in the eradication and first buffer zones. Cottonseed of the 'Qua-Paw' variety was used in order to get earlier fruiting. The trap crops were planted in late March or early April, 2 to 3 weeks ahead of the producer's cotton, in order for the trap-crop cotton to be larger, fruit earlier, and be generally more attractive to boll weevils. This early planting was accomplished with the help of a quarantine issued by the State regulatory agencies which stated that no producer cotton could be planted prior to April 15. This date was determined as the beginning of the optimum planting period for this area by the Cooperative Extension Service. The trap crops were baited with the synthetic boll weevil pheromone, grandlure, to attract into the trap crop any boll weevils that entered the field. In order to kill the weevils as they moved into the trap crop, the cotton received a 1 lb active ingredient per acre in-furrow treatment of the systemic insecticide aldicarb at planting and a 2-lb/acre sidedress treatment when the cotton reached the pinhead square stage approximately 6 to 7 weeks after planting. Foliar insecticide treatments of malathion or azinphosmethyl were also applied to some trap crops that were possibly still attractive to weevils after the aldicarb had lost its effectiveness.

Pinhead square treatment.—In 1972 a single insecticide treatment of azinphosmethyl of 0.25 lb/acre was applied to all cotton in the eradication and first buffer zones when the cotton was in the pinhead stage (June 1–21). This treatment was designed to kill any weevils that were not captured in traps or had not moved into the trap crop prior to the fruiting stage of cotton which would allow weevil reproduction.

Sterile releases.—Laboratory-reared, male boll weevils, sterilized with the chemosterilant busulfan, were aerially released on fields in the eradication and first buffer zones to eliminate reproduction by any individuals that may have survived the preceding treatments. A genetic strain of the boll weevil characterized by ebony body color was used in order to distinguish sterile from native weevils. Releases at weekly intervals started in early June and continued until mid-August. Free aerial releases were made from fixed-wing aircraft with a modified version of the release machine developed to drop sterile

TABLE 3.—*Average number of boll weevil pheromone traps in service per week in the eradication and first buffer zones during each month of 1971, 1972, and 1973*

Month	Eradication zone			First buffer zone		
	1971	1972	1973	1971	1972	1973
Jan.	...	479	800	...	544	831
Feb.	...	411	631	...	503	809
Mar.	...	90	710	...	130	883
Apr.	...	6,071	1,559	...	5,886	2,590
May	...	6,283	2,700	...	6,852	4,587
June	...	5,721	2,831	...	6,532	4,670
July	...	1,695	2,841	...	1,956	4,538
Aug.	113	594	1,405	157	1,036	1,864
Sept.	338	971	....	420	1,213	....
Oct.	528	1,228	....	544	1,567	....
Nov.	469	1,236	....	473	1,864	....
Dec.	482	633	....	505	892	....

pink bollworm moths.[3] Because of mechanical problems in the newly opened Robert T. Gast Rearing Laboratory at Mississippi State University, a shortage of sterile males for release occurred throughout the season in 1972. Table 4 shows the number of acres on which sterile releases were made and the average number of sterile males released each week in 1972.

In-season control.—In view of the poor in-season control in 1971, the in-season control phase of the experiment in 1972 was carried out by the APHIS eradication experiment personnel. All fields in the eradication and first buffer zones received five applications of azinphosmethyl at the rate of 0.25 lb/acre, or toxaphene + DDT + methyl parathion at the rate of 2 lb + 1 lb + 0.5 lb/acre, or DDT + azinphosmethyl at the rate of 1 lb + 0.25 lb/acre. Both fixed-wing aircraft and ground equipment were used to apply the treatments. Ground equipment was used only for supplemental treatment in some fields, while in others it was necessary to use ground equipment exclusively in order to obtain adequate coverage with the insecticide. Table 5 gives the application dates and the insecticide used on each application.

Because of field size, topography, or obstructions in the fields, there were 110 acres that were impossible to treat with aircraft or ground equipment in 1972. Through the cooperation of the Agricultural Stabilization and Conservation Service (ASCS), we were allowed to purchase and destroy the cotton in these fields. Payment was based on the ASCS projected yield records and current cotton prices.

Reproduction-diapause control.—Fall insecticide treatments for boll weevil reproduction-diapause control were initiated August 7 in the eradication and first buffer zones, August 21 in the second buffer zone, and September 7 in the third buffer zone. As in 1971, helicopters were used to apply the treatments in the eradication and first buffer zones and fixed-wing aircraft were used in the outer buffer zones. Ground equipment was also used for supplemental treatment in eradication and first buffer-zone fields that had obstructions or were otherwise too difficult to treat with aircraft and obtain adequate insecticide coverage. Azinphosmethyl, at the rate of 0.25 lb/acre, was applied as an ultra-low-volume spray with the aircraft, and in a water mixture with the ground equipment. A total of 13 applications were applied in the eradication and first buffer zones, 7 applications in the second buffer zone, and 4 applications in the third buffer zone. Applications were made on the same schedule as in 1971 and continued until frost on all cotton which had not been harvested and destroyed. Table 6 gives the application dates for each zone.

Cultural control—defoliation and stalk destruction.—Methods for defoliation were the same as described for 1971. In 1972, the crop matured approximately 1 month earlier than in 1971, and defoliation was accomplished from September 1 to 29 as cotton in the various areas

[3] Higgins, Albert H. 1970. A machine for free aerial release of sterile pink bollworm moths. U.S. Dep. Agric., Agric. Res. Serv. [Rep.] ARS 81–40, 10 pp.

TABLE 4.—*Number of acres in eradication and first buffer zones receiving sterile male boll weevils in 1972 and 1973, and average number of males released per acre*

Week of—	1972		1973	
	No. acres	Avg. No. males released/acre	No. acres	Avg. No. males released/acre
June 6	2,090	50	3,323	76
13	2,961	55	5,516	70
20	3,856	51	3,038	68
27	3,926	53	3,294	50
July 4	1,625	59	3,786	74
11	1,823	36	5,305	63
16	1,104	100	2,777	52
25	675	104	5,370	54
Aug. 1	896	124	5,074	57
8	792	129	3,545	70

TABLE 5.—*Insecticide used and inclusive application dates of in-season boll weevil control insecticide treatments in eradication and first buffer zones in 1972*

Application No.	Zone			
	Eradication		1st buffer	
	Insecticide	Date	Insecticide	Date
1	Azinphosmethyl	July 10–12	Azinphosmethyl	July 13–17.
2	do	July 16–19	do	July 19–22.
3	do	July 22–24	Azinphosmethyl + Tox–DDT–MP	July 24–30.
4	Tox–DDT–MP[1]	July 29–30	Tox–DDT–MP + DDT + azinphosmethyl	July 30–Aug. 2.
5	DDT + azinphosmethyl[1]	Aug. 1– 3	DDT + azinphosmethyl	Aug. 3–8.

[1] All Tox–DDT–MP and DDT applied for bollworm control.

reached the proper stage.

In 1972 cotton harvest was completed earlier and stalk destruction prior to frost was accomplished on 6,300 of a potential 6,811 acres.

1973

Pheromone traps.—Boll weevil traps were used in the same manner as in 1972 except that the number in service was cut to approximately one per acre. This was done because a longer-lasting formulation of grandlure was being used. Traps were in service at the one-per-acre rate from mid-April to early August. Table 3 gives the average number of traps in service per week in the eradication and first buffer zone during each month. Traps were also operated on approximately 600 acres in the northern portion of the second buffer zone.

Trap crop.—In 1973 the trap crops were planted by essentially the same methods as in 1972 except that we were able to avoid certain mistakes made in 1972, such as planting too deep, using a fertilizer of too high a nitrogen content, and placing the fertilizer too close to the seed. Also, cottonseed of the farmer's variety of 'Stoneville 213' was used, since many producers were not satisfied with the picking qualities of 'Qua-Paw' in 1972. Grandlure bait stations were located at 100-ft intervals the entire length of the trap crop.

Pinhead square treatment.—In 1973 a pinhead square treatment was applied to cotton only in those fields where two or more weevils per acre had been captured in traps by the time pinhead squares developed. This only occurred in 13 fields in the experiment.

Sterile releases.—Many of the rearing problems that existed in 1972 were solved, and throughout the 1973 season, sufficient numbers of sterile weevils were available for release in the eradication zone and a 5-mi buffer surrounding the eradication zone. An average of 50 to 76 sterile male weevils were released per

TABLE 6.—*Inclusive application dates of reproduction-diapause boll weevil control treatments applied in the boll weevil eradication experiment area in 1972*

Application no.	Zone			
	Eradication	1st buffer	2d buffer	3d buffer
1	Aug. 9–12	Aug. 7–12	Aug. 21–28	Sept. 7–10
2	12–17	12–15	Sept. 6– 7	19–21
3	18–19	17–19	12–14	Oct. 2– 5
4	22–25	22–25	21	16–20
5	27–29	27–29	Oct. 2– 3	.....
6	Sept. 3– 4	Sept. 3– 5	16–17	.....
7	11–14	11–13	Oct. 30–Nov. 1	.....
8	18–20	18–20	.....	.....
9	26–28	26–28	.....	.....
10	Oct. 5– 8	Oct. 5– 8	.....	.....
11	16–17	16–17	.....	.....
12	Oct. 30–Nov. 1	Oct. 30–Nov. 1	.....	.....
13	Nov. 9–11	Nov. 9–11	.....	.....

acre per week from June 4 to August 10. Table 4 gives the number of acres and the average number of sterile males released per acre in 1973.

In-season control.—Initial criteria for in-season control treatments in the eradication zone in 1973 required treatment if (1) a total of at least two boll weevils per acre were captured in traps from beginning of trapping to the finding of two widely separated oviposition-damaged squares or, (2) if three or more oviposition-damaged squares were found (regardless of trap data). It was soon determined that some squares appearing to have oviposition damage did not, and that sterile eggs were being deposited by native females as well as by the few sterile females (1%–2%) that were being released with the sterile males. In view of this, treatments were applied only in fields where, though the use of field survey, square dissection, and egg hatch data, it was determined that a native boll weevil infestation existed. Where the infestation could be delimited to a small, localized spot in the field, only spot treatment was made. The first buffer-zone treatment was made to fields where an infestation was found and appeared to have the potential for rapid buildup. In the eradication zone, pesticides were applied with ground equipment except when the fields were too wet, in which event aircraft was used. Depending upon the type of field, obstructions, etc., both ground equipment and aircraft were used in the first buffer zone. Azinphosmethyl at 0.25 lb/acre was applied at 3-day intervals. Table 7 gives the number of fields, acres, and treatment dates. In 1973, 740 acres in the northern portion of the second buffer also received two aerial treatments of azinphosmethyl from July 16 to 24 to prevent population buildup which would threaten the test with migrating boll weevils.

EVALUATION

The PBWEE was evaluated as follows:

1. An intensive visual insect survey was made during each week of the cotton-growing season. In the eradication and first buffer zones, an infestation survey was made in each field each week if rain or insecticide application did not prevent. In the eradication and first buffer zones, an infestation survey was made in all fields of 10 acres or less. In fields over 10 acres surveys were made for each 10-acre increment. In the second and third buffer zones, infestation surveys were made on a per-field basis, and population estimates were made by scouting a representative number of fields each week. Prior to squaring of the cotton, row counts for live adult boll weevils were made by examining 50 ft at each of five spots in the trap crop, and 50 ft of farmer cotton. During the squaring period surveys were made by examining cotton squares in a diagonal route across the field, and the level of infestation was determined as percent oviposition-damaged squares. During 1971 and up to the week of June 19, 1972, 100 squares per field were examined, after which time 200 squares per field were examined. In 1973 at least 300 squares per field were examined. In 1973, if a square was found that con-

TABLE 7.—*Number of fields and acres treated with insecticide during indicated weeks in eradication and first buffer zones in 1973*

Week of—	Zone			
	Eradication		1st buffer	
	No. fields	No. acres	No. fields	No. acres
June 6	0	0	1	6
13	0	0	1	5
20	10	74	8	50
27	16	80	31	245
July 4	2	10	5	23
[1]11	2	5	53	451
16	13	68	41	348
25	30	142	26	209
Aug. 1	33	165	39	291
8	18	87	..	...

[1] All treatments applied prior to the week of July 11 were based on trap catch or suspect oviposition-damaged squares. After this date they were based on native boll weevil infestations.

tained a viable egg or an immature boll weevil form, surveys were immediately intensified in that particular field to determine the degree of infestation and whether it was localized or general. As squaring of the cotton began to terminate, surveys were made by "shagging" the adult weevils from 25 ft of cotton row at each of four spots to determine the estimated number of adults per acre. Surveys at all times during the season were oriented to the largest, greenest cotton in the field, which was more attractive to boll weevils. This caused the population estimates to be biased in favor of detecting an infestation.

2. Ground trash from potential hibernation sites around the fields was collected and examined in the fall and spring of each year to determine the approximate number of boll weevils per acre that had survived the winter.

3. Grandlure-baited pheromone traps were used to detect possible low-level boll weevil infestations and "hot spots," in addition to being used for population suppression.

4. In addition to manual visual surveys, tractor-mounted insect collecting machines were used to make intensive boll weevil surveys in 25 fields in the eradication and first buffer zones in 1973.[4]

5. In 1973 all cotton squares showing possible boll weevil oviposition damage were collected from the field and brought into the laboratory where the squares were dissected and examined for the presence of any boll weevil eggs or immature forms. All eggs were held to determine hatch, and all immature forms were held for adult development. The results obtained enabled the determination of active boll weevil infestations and an evaluation of the effectiveness of the sterile male releases.

6. In-field traps were placed in 4 fields in each of the eradication and first buffer zones as an additional method of evaluating the effectiveness of the insecticide treatments and sterile-male releases in eliminating low-level populations.

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[4] Lloyd, E. P. 1973. Intensive sampling in eradication and first buffer areas, Pilot Boll Weevil Eradication Experiment, 1973. Special Report, Boll Weevil Research Laboratory, Agricultural Research Service, Mississippi State, Miss. Mimeo. 11 pp.

ACTIVITIES OF THE MISSISSIPPI COOPERATIVE EXTENSION SERVICE IN THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT, 1971-73

By David F. Young, Jr.[1]

The Mississippi Cooperative Extension Service (MCES) first became involved in the Pilot Boll Weevil Eradication Experiment (PBWEE) when Robert Coker asked me to serve on the National Cotton Council's Special Study Committee on Boll Weevil Eradication in early 1969. After that assignment, I was asked to serve on the Technical Guidance Committee for a PBWEE in south Mississippi, Louisiana, and Alabama, and also asked to serve on the Technical Subcommittee to develop the overall plan for boll weevil eradication.

Later in 1969, the Boll Weevil Eradication Study Committee decided that it might be possible to eradicate the boll weevil with currently known techniques. That decision having been reached, it became necessary to select a suitable location for the experiment. The MCES made a survey of 37 southern counties to determine whether the area could serve as a site for the eradication effort. Within this area, we had typical farm conditions, with high and hard-to-control boll weevil populations, plus isolation to the south. We felt that if the boll weevil could be eradicated in this area, eradication would be possible in any other part of the Cotton Belt.

We found that within a 75-mi radius, using a point in Marion County near the Louisiana line as the center, there were 38,555 acres of cotton planted in 1968 on 7,764 farms. Using a 100-mi radius, we found that the acreage increased to 60,339 acres and was grown on 10,116 farms. By shifting the center of the core area to any other given point—to Prentiss, Miss., for example—the acreage varied considerably. When the Site Selection Committee visited Mississippi in late 1969 and was presented this information and other data, it decided that Mississippi met all the criteria for the eradication experiment, and the southern part of Mississippi and parts of Louisiana and Alabama were thus designated as the site within which the experiment would be conducted.

It was not possible in 1970 to obtain the necessary funds to begin the large-scale PBWEE, but funds were available to begin preliminary testing of some of the techniques to be used. A small-scale test was carried out and it served to identify some of the problems peculiar to this particular area. Also included in this trial were several combinations of population suppression techniques which were used later in the course of the large PBWEE.

The Special Boll Weevil Committee met early in 1971 in Atlanta and decided to delay for one year the large-scale south Mississippi PBWEE because of insufficient funds. Following this meeting, we in Mississippi realized that the cotton acreage to be planted in 1971 was going to be considerably less than it had been in the previous year. This was so because of the cotton program, new at that time, in which many small producers were either leasing or selling their allotments to farmers in the Mississippi Delta.

Having realized that this change was taking place, we again contacted the county agents for information regarding cotton acreage to be planted within the area. When the Technical Guidance Committee for the PBWEE met at Mississippi State on March 18, 1971, it was determined that approximately 25,500 acres of cotton were to be planted within the area in a 75-mi radius zone. The drastic reduction in cotton acreage—approximately 50%—made it feasible to conduct the experiment in 1971 with the $2 million then committed.

The Extension Service's training for the county agents in the south Mississippi area, however, began in 1970, when it was decided that an area consisting of 11 counties would be in a small boll weevil suppression program that year. Within these counties were 431 cotton producers growing 4,400 acres of cotton. We initially called all of our county agents together to fully explain the program. We also requested members of the operations, research, and regulatory groups

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to meet with us to discuss all aspects of the program.

During 1970, our principal activities were to get the farmers affected by the program to agree upon the diapause applications to be used on their farms. They were also urged to do as much stalk destruction as possible and to comply with the program generally. We knew we needed 100% cooperation in this program for it to be a success. A compliance form was adopted for all of the farmers to sign. The county agents; district entomologists for the Division of Plant Industry, Mississippi Department of Agriculture and Commerce; and members of the operations group delivered the forms to the farmers. This took a great deal of legwork, but it was very successful. I might add that in 1971, prior to beginning the large experiment, the signing of compliance forms was abandoned when the Division of Plant Industry decided to give public notice in regard to the program. This legal move was very helpful to everyone.

It was also necessary to enroll the county agents to help locate all the cotton fields in the counties where the program was being developed.

It should also be pointed out that in early 1970, the Extension Service was very much involved in securing funds for the Boll Weevil Rearing Facility at Mississippi State. We requested $350,000 from the 1970 legislature, and requested an additional $170,000 for the structure in 1971.

In preparation for the PBWEE we gave the agents in the subject area considerable training in cotton insect control, fertilization, the use of herbicides, defoliation and other techniques to bring them up to date on good agronomic practices. It should be kept in mind that this program was carried on in an area where cotton was gradually fading out as the major income crop, and that our agents therefore needed refresher courses in cotton production.

Following agent training, we located the eradication area boundaries for the agents. In some cases, the boundary of the eradication area split counties, and we suggest that this not be done in future eradication programs because of the problems it creates for the county agents. The farmers in split counties did not understand why one side of the county was involved in an eradication experiment while the other side was not. This created some ill-will which was difficult to overcome.

We also acquainted the agents with quarantine measures involving cotton's being brought into the area for ginning and then taken back outside the area. A great deal of prepared information and written data were given to the agents outlining all the steps in the program and giving answers to many of their questions. We also supplied them with a list of personnel working with the various agencies. Finally, we prepared publicity for the agent's use.

We set the following goals for the county agents: (1) Cotton producers were to improve their skills in the use of improved cotton-production practices. It was our goal to get the best possible in-season insect-control program carried out in both core and buffer areas. (2) Core area cotton producers were to understand the nature and the importance of the PBWEE, and cooperate with it. They were also to increase their net income from cotton.

To accomplish these major objectives, it was necessary for the county agents to discuss the program with key leadership figures such as ginners, seed fertilizer dealers, vocational-agriculture instructors, the coordinating council, co-op managers, and key farmers within their area. In establishing the county committees, it was important to get the right men on the right committees and to have all major areas of cotton production represented by cotton producers. The objectives of the county cotton production committee were to (1) review and understand the PBWEE, (2) review, develop, or approve plans for implementing the program, (3) help carry out the program by actively supporting it, and willingly assume certain responsibilities for carrying out the program when requested, (4) set up subcommittees to deal with and make recommendations concerning problems in the county, (5) help select and approve necessary subcommittees, which were to have basically the same responsibility as the county committee, but on a community basis, (6) be concerned with evaluation and make adjustments when needed, (7) alert all cotton producers of the program and get 100% participation (it would only take one man to create a problem in the area), (8) help monitor the effects of the program on nontarget animals and insects, such as honeybees, quail, fish, etc., and if abnormal animal mortalities or behavior occurred, to contact the Department of Wildlife and Fisheries through Farrell Boyd, U.S. Department of Agriculture, or H. C. Mitchell with the MCES.

After the agents organized the counties, they did everything they could possibly do to motivate the farmers in uniting their efforts to control the boll weevil during the growing season. Our principal goal was to establish the best in-season control program possible within the area. In 1971, there were 23,500 acres of cotton planted within the experimental area. The average size of a farm was about 7½ acres, so we were obviously dealing with very small producers for the most part, though we did have a number of large and very capable cotton producers within the area. Many of the producers could not afford to buy modern pesticide equipment for applications. We estimated in 1971 that about 25% of the farmers in the area carried out a good program, 25% a fair program, and the remainder from a poor program to no program at all. Many of the small cotton producers within the area only planted cotton for the Government payments they received. Much of the cotton was simply planted and abandoned.

Mississippi Cooperative Extension Service personnel organized monthly progress meetings at Prentiss Eradication Headquarters in Prentiss, Miss. Representatives from Federal and State organizations involved in the experiment used these meetings to discuss progress or problems. These were key meetings which helped insure a close working relationship between the 15 agencies involved. Extension personnel also established work sessions for work-unit supervisors and county agents to give them the opportunity to discuss eradication problems. These sessions were held bimonthly, or as needed during the cotton-growing season.

Extension educational channels were also used to minimize the theft of boll weevil traps placed in the fields at the start of the program.

On July 1, 1971, H. C. Mitchell was hired and placed in the area as Extension entomologist to carry out the MCES's activities along with the county agents. Mitchell served as liaison between the various agricultural agencies involved in the program, and in many cases served as a troubleshooter when we found a farmer who was unwilling to carry out certain parts of the program. Mitchell was one of the real keys to the success of the eradication program. His experience in working with farmers and ability to get people to work together was appreciated by everyone. In a beltwide program, it will be absolutely necessary to have an experienced Extension entomologist in each State to devote his entire time to the program. It is important that he begin organizing before the eradication program moves into the State.

Several methods were used to inform cotton producers of the experiment and the ways in which they would benefit from it. Countywide producer meetings, community meetings, individual contacts, radio, television, and newspapers were used to spread information concerning the experiment. Weekly weevil-eradication newsletters prepared by the Extension Service entomologists and mailed by the county agents helped to keep cotton producers informed of current developments. Boll weevil infestation counts were obtained through the operations office each week and mailed to producers via the county agents. This was extremely helpful to farmers within the area since they were able to use the scouts' reports in determining when to apply insecticides for control. Overall, 64 different newsletters were prepared and mailed to the farmers, amounting to 97,000 individual letters.

As the experiment progressed, the boll weevil eradication film and slide sets were widely used for the promotion and explanation of the eradication program. These educational means were continually used to supplement the news media in keeping producers and the general public informed. A continuous flow of news and information about the experiment thus went to both the producers and the public. If problems arose, Extension personnel assisted first in identifying them, and then in finding a solution to them.

We gained a great deal of valuable experience in dealing with cotton producers in the PBWEE, and we feel that this knowledge will be of great value in future beltwide programs.

Optimism is high among our cotton producers in regard to the success of the program. Yields were increased on many, many farms, especially on those farms where very little insect control was ever carried out by the producer. We are convinced the boll weevil can be eliminated as an economic pest and will continue to support the beltwide program every way possible.

REGULATORY ACTIVITIES CARRIED ON UNDER THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT, 1971-73

By O. T. Guice, Jr.[1]

The regulatory activities connected with the Pilot Boll Weevil Eradication Experiment (PBWEE) were relatively minor as compared to an all-out attempt to eradicate the boll weevil.

In connection with the PBWEE, which covered all or parts of 33 counties in Mississippi, parts of 2 counties in Alabama, and parts or all of some 7 parishes in Louisiana, the Division of Plant Industry, Mississippi Department of Agriculture and Commerce, with Division headquarters at Mississippi State, Miss., adopted a boll weevil quarantine on July 1, 1971. The quarantine had several purposes which were essential to demonstrating eradication of the boll weevil in the eradication or core area of the experiment. One purpose was to prevent the growing of noncommercial plantings of cotton, such as cotton planted in flowerbeds around homes and service stations for ornamental purposes. Such cotton was destroyed on several occasions, one or two of which caused slight problems. Seeing to the destruction of such cotton can be a very delicate matter. Very fortunately, however, we were able to see that all such cotton was destroyed.

Another purpose of the quarantine was to establish regulated articles or products which might be responsible for accidental movement of the boll weevil in any living stage of development into the eradication area from the buffer area and other regulated areas outside the eradication area. Regulated articles or products included (1) the boll weevil in any living stage of development, except sterile releases, (2) seed cotton, (3) gin trash, (4) mechanical harvesting equipment, and (5) any other products, articles, or means of conveyance of any character whatsoever not covered by the previously mentioned, which might present a hazard of spread into the eradication area.

On February 28, 1972, the quarantine was amended to establish an optimum planting date of April 15 in the eradication and first buffer areas, before which no cotton could be planted by farmers. This change was made to allow the planting of trap-crop rows of cotton 1 to 2 weeks before the regular crop was planted. Excellent publicity was given to this phase and all other phases of the program by the Mississippi Cooperative Extension Service, the U.S. Department of Agriculture, the Division of Plant Industry, and other cooperating agencies, by means of varied news media, including newspapers, radio, television, and numerous letters sent through county agents to every cotton producer. Talks were also made at various agricultural clubs, at the Farm Bureau in various counties, at meetings of ginners, civic organizations, bankers, and others concerning the program and the quarantine.

Results were most gratifying, and except for possibly less than one-half dozen cases involving relatively minor instances, quarantine and regulatory problems were fewer than in perhaps any quarantine program with which I have been associated in some 35 years in dealing with regulatory matters. In only one case did we have to go to the point of notifying a producer that an injunction would be served to prevent his interference with the program. This resulted largely from the fact that he did not fully understand the goals of the program, and after they were fully explained to him we did not have to ask the court to serve the injunction.

It is my belief that the PBWEE, in a large

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measure, demonstrated that the boll weevil can be eradicated. When an all-out boll weevil eradication program is started, there will no doubt be some refinements and improvements in the techniques used in the PBWEE which will make eradication more practical and less expensive. Some of these include improvement in rearing techniques, a method of determining when eradication has been accomplished, and sterilization procedures which may eliminate sexing, which has been quite costly. The cotton industry, which put so much effort and money into the PBWEE, will need to continue its efforts with the full realization that the industry will have to carry a good part of the expense for the eradication program.

Government will nonetheless have considerable responsibilities in any future eradication efforts, especially when such programs extend across a number of State boundaries. Such an effort will surely demand careful and effective regulation. In progressing into a multi-State eradication program, there are a few things which must be incorporated into regulations backed by fully enforceable laws. Some of these are as follows: (1) There cannot be any compromise as to whether or not a cotton producer will or will not participate in an eradication program. Compulsory 100% participation is an absolute necessity in a boll weevil eradication program. (2) Elimination of injunctive procedures should be included in any regulation and backed up by appropriate legislation, since any injunctive procedure may delay necessary treatments and thereby make eradication impossible or seriously jeopardize an eradication program. Such legislation may go all the way back to the basic rights of an individual under the Constitution. (3) Provisions for establishing of eradication zones would be necessary. (4) Right of access and entry to any property in an eradication zone to see that appropriate eradication measures are carried out on all cotton on a 100% basis is necessary. Such measures may include the following: (a) establishment of optimum planting dates, (b) trap crop plantings, (c) pheromone traps and bait stations, (d) sterile boll weevil releases, (e) pinhead square treatment, (f) in-season control, (g) fall reproduction-diapause treatments, (h) crop termination dates, (i) stalk destruction dates, and (j) other measures which may later prove effective. (5) Authority to prohibit noncommercial growing of cotton in eradication zones, such as the planting of cotton in flowerbeds or its growth for other ornamental purposes. (6) Authority to regulate the movement of seed cotton, gin trash, mechanical harvesting equipment, or any other articles which might move boll weevils into the eradication zone, or move weevils from one part of the zone to the other. (7) Authority to allow destruction or treatment of volunteer cotton and to eliminate boll weevil host plants in an eradication zone. (8) Authority to make mandatory the reporting of all cotton acreage being grown. (9) Authority to make mandatory the growing of cotton in a workmanlike manner, including practices necessary to give maximum yields, such as weed control and proper boll weevil control. (10) Authority to purchase limited acreage of cotton which, because of field size, barriers, economics, etc., could not be properly treated to insure success of an eradication program. (11) Authority to prohibit unauthorized persons and livestock from entering cottonfields during certain eradication program operations.

U.S. Senate Bill 517, passed by the first session of the 93d Congress, amending the Agricultural Act of 1970, would seem to give the Secretary of Agriculture authority to incorporate the control measures listed above into regulations, presumably in the form of a Federal quarantine.

BOLL WEEVIL POPULATION LEVELS DURING THE IN-SEASON AND REPRODUCTION-DIAPAUSE CONTROL PHASES OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By F. J. Boyd[1]

1971

It was estimated that approximately 50% of the cotton in the Pilot Boll Weevil Eradication Experiment (PBWEE) area did not receive any in-season boll weevil control insecticide treatments in 1971. Lack of boll weevil control on this much of the acreage allowed a rather high infestation to develop. During early July the percentage of squares with boll weevil oviposition damage ranged from 22.8% in the first buffer zone to 56.7% in the third buffer zone (fig. 1). Throughout the squaring period, the percentage of oviposition-damaged squares generally ran lower in the first buffer zone, and in the eradication zone was as high or higher than that in the other zones. The majority of the cotton in the first buffer zone was considered to have received more in-season control, while the majority of the cotton in the eradication zone probably received less in-season control than either of the other zones. Reduction in the square infestation as a result of the malathion treatments for reproduction-diapause control (initiated August 9 in the eradication and first buffer zones, and September 1 in the second and third buffer zones) was gradual since continuous adult emergence occurred from the large number of eggs deposited in squares and bolls during July.

As squaring of the cotton began to terminate, live adult weevil surveys were made beginning with the week of September 1 in the eradication and first buffer zones, and the week of September 27 in the second and third buffer zones. When these surveys began, adults averaged 1,700 per acre in the eradication zone, 1,540 in the first buffer zone, 587 in the second buffer zone, and 2,720 in the third buffer zone (fig. 2). The last population survey of the season, made the week of November 11 just prior to the first frost, showed that the malathion treatments and defoliation of the cotton had reduced the average number of adults per acre to 142 in the eradication zone, 108 in the first buffer zone, 16 in the second buffer, and 325 in the third buffer.

Following the first frost, ground-trash samples were collected from November 15–30. The number of diapausing boll weevils in ground trash ranged from a low of 130 per acre in the

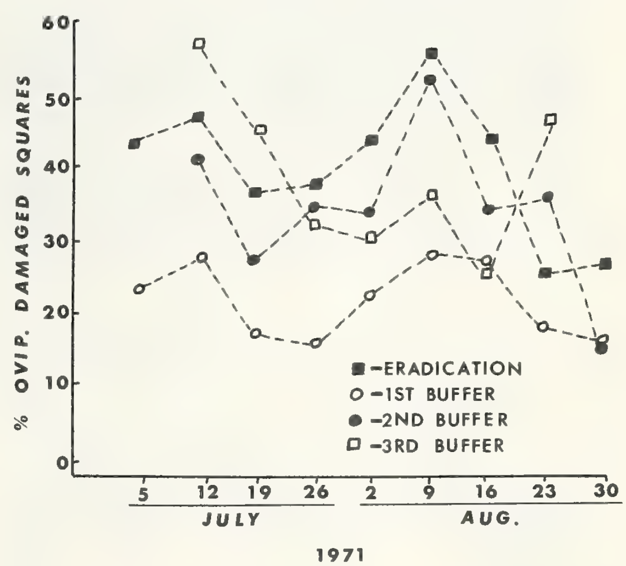

FIGURE 1.—Percent boll weevil oviposition-damaged squares in the zones of the Pilot Boll Weevil Eradication Experiment in 1971.

[1] Entomologist, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Prentiss, Miss. 39474.

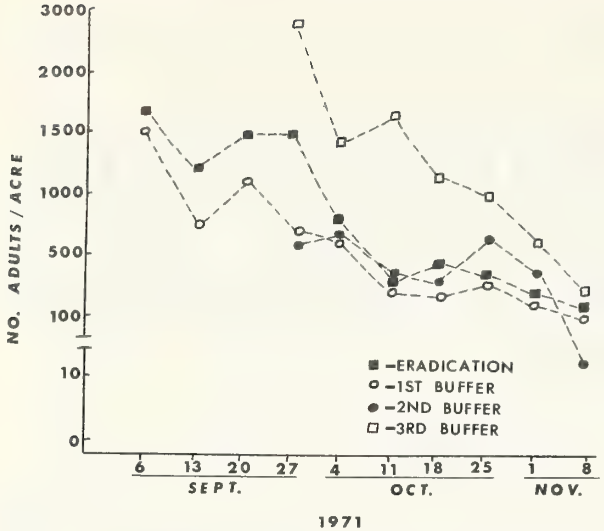

FIGURE 2.—Estimated number of adult boll weevils per acre in the zones of the Pilot Boll Weevil Eradication Experiment in 1971.

eradication zone to a high of 1,492 per acre in the adjoining untreated area outside the experimental area (table 1). The spring ground-trash samples for overwintered boll weevils were collected March 1–15. The overwintered population ranged from a low of 215 per acre in the first buffer zone to a high of 778 per acre in the adjoining untreated area. This data indicated that only very low weevil mortality occurred during the winter.

The importance of stalk destruction was emphasized when boll weevils were discovered overwintering in dried bolls which remained on undestroyed cotton stalks during the winter of 1971–72. Dried boll dissections on January 20, February 12, and February 28, 1972, showed 27, 44, and 33 adults per acre overwintering in dried bolls in the eradication zone, and 44, 22, and 0 adults per acre overwintering in the first buffer zone, respectively.

1972

During late May and early June of 1972, the adult boll weevil population found in trap crops ranged from 25 to 40 per acre in the eradication zone. However, these populations were not representative of the total acreage of cotton since the trap crops are designed to aggregate boll weevils in a localized area of the field.

Starting with the week of June 14, square counts were made to determine the infestation level. By the last week in June, 74% of the farmer cottonfields in the eradication zone were infested with an average of 8% oviposition damage (fig. 3). This low-level, but general, infestation indicated that populations of boll weevils of possibly 10 to 20 per acre had survived all suppression measures of the preceding fall and spring. It was felt that this was caused by several factors which included: (1) An inadequate in-season control program during 1971 had resulted in high populations of boll weevils in the fields when the scheduled reproduction-diapause treatments started. These populations were so high that even control at 95% plus allowed many weevils to attain diapause during the treatment period. It is also possible that considerable numbers entered diapause in late summer prior to the initiation of treatment. (2) Because many fields were difficult to treat by aircraft, pesticide applications had not been completely efficient.

Accordingly, it was decided that program personnel would apply the in-season control necessary to keep boll weevils below economically damaging levels in the eradication and first buffer zones in 1972. These treatments were initiated July 10 and continued until the sched-

TABLE 1.—*Results of ground-trash samples collected in the Pilot Boll Weevil Eradication Experiment area in 1971, 1972, and 1973*

Zone	Trash sampled (yd²)				Avg. No. diapausing boll weevils/acre			
	1971	1972		1973	1971	1972		1973
	(fall)	Spring	Fall	(spring)	(fall)	Spring	Fall	(spring)
Eradication	600	539	600	565	130	395	0	0
1st buffer	520	517	580	580	235	215	0	0
2d buffer	275	310	140	0	629	484	380	...
3d buffer	320	210	135	0	301	392	143	...
Untreated area	290	230	150	110	1,492	778	645	440

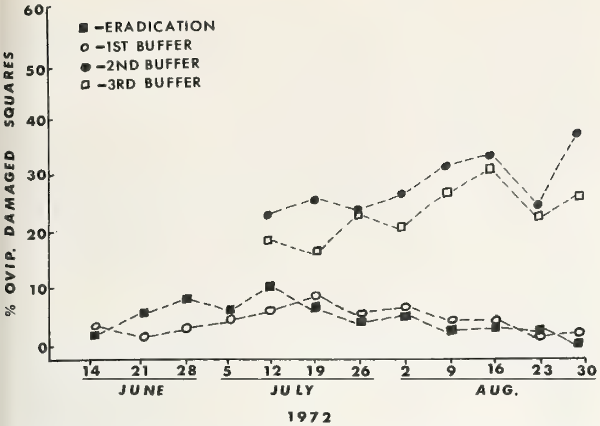

FIGURE 3.—Percent boll weevil oviposition-damaged squares in the zones of the Pilot Boll Weevil Eradication Experiment in 1972.

uled reproduction-diapause treatments started on August 7. Fields were also classified as to requirements for supplemental ground-equipment treatments, which were applied on the same schedule as the aerial treatments.

The in-season control treatments of azinphosmethyl (at 0.25 lb/acre) or toxaphene + DDT + methyl parathion (at 2 lb + 1 lb + 0.5 lb/acre) caused a continuous reduction in the percentage of oviposition-damaged squares, and by the week of August 30, boll weevil oviposition damage in the eradication zone was down to 0.7% (fig. 3).

In the first buffer zone the average number of adults found in trap crops in late May and early June ranged from 10 to 15 per acre. Oviposition-damaged squares in farmer cotton ranged from 1.3% to 8.1% in June, July, and August (fig. 3). Infestation levels in the first buffer zone were slightly lower in the early part of the season, and slightly higher in the latter part, as compared to infestation levels in the eradication zone.

For the weeks of July 12 through August 30, infested squares in the second and third buffer zones ranged from 15% to 36%. The infestation in the third buffer was slightly lower than that in the second buffer throughout the squaring period (fig. 3).

As the cotton began to terminate in early September, live adult weevil surveys were used to measure the population levels. From early September to mid-October the population in the eradication zone fluctuated from 1 to 13 adults per acre (fig. 4). The week of October 18 no adults were detected in field surveys, and the population remained at zero or a nondetectable level throughout the remainder of the season.

The adult population in the first buffer zone generally followed the same trend as that in the eradication zone, but was an average of 2.4 times higher. By early November the population had reached a nondetectable level.

Although the percentage of boll weevil oviposition-damaged squares ran higher in the second buffer zone, the adult population was considerably lower than in the third buffer zone. In the second buffer zone the average number of adults ranged from a high of 513 per acre in the week of September 27 to a low of 43 per acre in the week of November 8. The population in the third buffer zone ranged from a high of 955 adults per acre in the week of September 13 to a low of 108 adults per acre in the week of October 25.

In comparing boll weevil infestation data collected in 1971 and 1972, it is apparent that reproduction-diapause treatments must be preceded by a good in-season boll weevil control program if the population is to be reduced to a very low level, and if the most effective operation from the other suppression measures is to be obtained. This is shown by the fact that in 1972 boll weevil oviposition-damaged squares in the eradication zone were 90% fewer than in 1971, and the average number of adults per acre was 99.6% fewer. It should be noted, however, that reproduction-diapause treatments alone considerably reduce the population. In the second

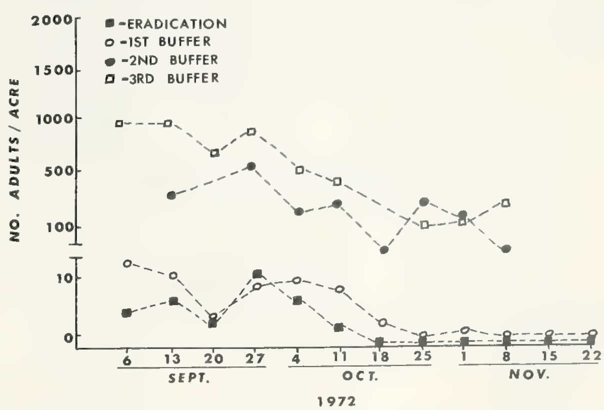

FIGURE 4.—Estimated number of adult boll weevils per acre in the zones of the Pilot Boll Weevil Eradication Experiment in 1972.

buffer zone, which received seven insecticide treatments in the fall, the adult population was an average of 75% smaller than in 1971, and in the third buffer zone, which received only four insecticide treatments in the fall, the adult population was an average of 55% smaller. These results show that the diapause program in 1971 resulted in a considerable reduction in the population pressure in 1972, but with the population size that existed in 1971, diapause control without in-season control allowed a sizable weevil population to attain diapause and overwinter.

Ground-trash samples collected in the fall of 1972 revealed no boll weevils in trash in the eradication or first buffer zones, as compared to 130 and 235 weevils per acre respectively, in 1971 (table 1). An average of 380 per acre was found in the second buffer zone, 143 per acre in the third buffer zone, and 645 per acre in the untreated area outside the experimental area. Spring ground-trash samples still detected no weevils in the eradication and first buffer zones as compared to an average of 440 per acre in the outside untreated area. Samples were not collected in the second or third buffer zones in the spring of 1973. The results of the fall and spring trash samples in the eradication and first buffer zones reinforced the survey results, which showed that the population had been reduced to an extremely low level.

1973

Table 2 gives the number of native and sterile adult boll weevils found in visual surveys in the eradication zone in 1973, as well as the number of fields they were found in. From May 7 through August 10, nine native adults were found in nine trap crops, with seven weevils found in June. In farmer cotton 19 native adults were found in 15 fields. Four of these were found in June, five in July, and six in August (in unit 5). All of the 15 weevils found in July and August, with the exception of one found in unit 2, came from the northern one-third of the eradication zone (units 3, 4, and 5), which became the sensitive area in the eradication zone. Based on visual surveys, the overflooding ratio of steriles to natives for the season averaged 56.4 to 1 in trap crops and 11.6 to 1 in farmer cotton.

In visual surveys for oviposition-damaged squares in the eradication zone, 2,279 suspect squares were detected in fields in 183 collections (table 3). Discounting repeat collections during the same weeks or successive weeks, collections were made in 77 individual fields, the majority of them in the northernmost unit (unit 4). Dissection of these squares yielded 288 immatures and 958 eggs.[2] The weeks of July 11, 18, and 25 were the most critical. During this period 68% of the squares, 78% of the immatures, and 76% of the eggs were detected. In the week of August 8, the last of the experiment, eggs, of which none hatched, were detected in four fields and immatures were found in two fields, both in unit 5. Eleven larvae were found in one of these fields (the first detection), while one pupa was found in the other field, in which an immature had been detected the previous week.

The detection and determination of a native

[2] For detailed data on egg hatch and immature development, see E. P. Lloyd et al., "Release of Sterile Male Boll Weevils in the Pilot Boll Weevil Eradication Experiment in 1972–73," this volume.

TABLE 2.—*Number of live adult boll weevils found in cotton in the eradication zone from May 7 through August 10, 1973*

Crop and weevil type	No. adults found	No. fields with adults found[1]
Trap crop:		
Native	9	9
Sterile	508	214
Farmer cotton:		
Native	19	15
Sterile	220	137

[1] Total of 236 cottonfields in the eradication zone.

TABLE 3.—*Results of detection surveys for suspect boll weevil oviposition-damaged squares in the eradication zone in 1973*

Week of—	No. collections[1]	No. damaged squares	No. immatures	No. eggs
June 13	2	11	0	9
20	17	226	5	59
27	23	215	2	88
July 4	14	105	1	11
11	33	474	36	209
18	45	590	140	266
25	33	491	50	248
Aug. 1	12	123	42	55
8	4	44	12	13
Total	183	2,279	288	958

[1] Collections made in 77 individual fields.

boll weevil infestation in 1973 was difficult under the low-level population conditions that existed. In the evaluation of this test, it was known that (1) a few sterile females were released which were capable of depositing sterile eggs and (2) native females would deposit sterile eggs after mating with sterile males. Therefore, to identify an incipient native infestation, it was necessary to go beyond the mere detection of oviposition. The determination of egg hatch and larval development were extremely important, since the sterile males caused a substantial reduction in the normal egg hatch during the season.

Based on detection surveys and square-dissection records, the number of fields and acres in which incipient infestations of boll weevils were detected in the units of the eradication zone in 1973 is given in table 4. Out of a total of 1,817 acres in 236 fields, boll weevil infestations were detected in 34 fields (14.4%) amounting to 167 acres (9.2%). Sixty-one and eight-tenths percent of the infested fields and 68.2% of the infested acreage was located in unit 4, which was adjacent to considerable boll weevil infested cotton acreage outside the eradication zone. Twenty-three and five-tenths percent of the infested fields was in unit 5 and 14.7% was in unit 3. No infestations were detected in units 1, 2, or 6. Figure 5 shows the location of the infested fields, all of which were located in the upper one-third of the zone.

Each field found infested was treated with azinphosmethyl at 0.25 lb/acre at 3-day intervals. Extensive surveys in each infested field showed that these treatments, plus the continued sterile releases, stopped boll weevil reproduction in all fields, with the exception of one field in unit 5, which was first detected the week of August 8, so near the termination of the experiment that it was not possible to execute the necessary suppressive measures.

It was very critical that surveys be conducted in a biased fashion in order to insure detection of an incipient infestation and the application of elimination measures before any sizable population increase occurred. Biased surveys were considered the final and most important element in conducting a successful program, since we expected late-emerging overwintered weevils and possibly migrant weevils to start incipient

TABLE 4.—*Total number of fields and acres and number of infested fields and acres in the units of the eradication zone and the week detected, 1973*

Unit	Total No./unit		Week of— July 11		July 18		July 25		Aug. 1		Aug. 8		Total infested—	
	Fields	Acres	Fields	Acres	Fields	Acres	Fields	Acres	Fields	Acres	Fields	Acres	Fields	Acres
1	31	276	0	0	0	0	0	0	0	0	0	0	0	0
2	40	293	0	0	0	0	0	0	0	0	0	0	0	0
3	42	402	0	0	2	10	2	5	1	5	0	0	5	20
4	45	274	6	37	[1]10	50	5	27	0	0	0	0	21	114
5	41	287	0	0	0	0	4	13	3	18	1	2	8	33
6	37	285	0	0	0	0	0	0	0	0	0	0	0	0
Total	236	1,817	6	37	12	60	11	45	4	23	1	2	34	167

[1] One of these trap crop only.

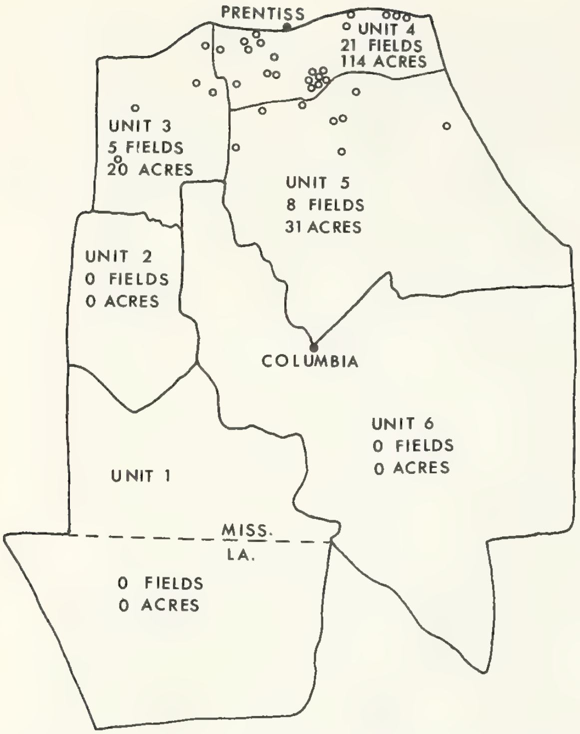

FIGURE 5.—Location and number of boll weevil infested fields and acres detected in the units of the eradication zone in 1973.

infestations. The sampling methods employed by APHIS personnel in detecting infestations were as effective as the methods used in the intensive sampling study.[3]

From the week of May 9 through August 8 in the first buffer zone, 49 native adults were found in 29 trap crops, and 39 native adults were found in 29 fields of farmer cotton by visual survey (table 5). All native adults were found in the trap crop during the weeks of May 9 through July 11, while only one native adult was found in farmer cotton prior to the week of July 4. Based on visual survey, the ratio of sterile to native adults during the season averaged 1 to 1 in trap crops and 0.8 to 1 in farmer cotton in the first buffer zone. This is a much lower ratio than that which existed in the eradication zone, but is based on all fields, rather than only on fields in which weevils were released in each particular week.

[3] See Lloyd and Scott, "Intensive Sampling of Twenty-five Selected Fields in Eradication and First Buffer Areas of the Pilot Boll Weevil Eradication Experiment in 1973," this volume.

Two hundred and thirty square surveys in the first buffer zone detected 2,072 suspect oviposition-damaged squares in what amounted to 136 individual fields (table 6). These squares contained 493 immatures and 333 eggs, of which the majority came from units 2 and 3. These units were directly north of the eradication zone and adjacent to the greatest amount of boll weevil infested cotton acreage in the second buffer zone.

Boll weevil surveys in the northern portion of the second buffer zone monitored population buildup so that insecticide treatments could be applied to prevent development of large numbers of weevils which might migrate into the eradication zone. From mid-June to late June the adult population in the area ranged from an average of 40 to 87 per acre (fig. 6). The percentage of fields where adults were found increased from 14% in mid-June to 64% by late June. When infested square surveys were begun

TABLE 5.—*Number of live adult boll weevils found in the cotton in the first buffer zone from May 7 through August 8, 1973*

Crop and weevil type	No. adults found	No. fields with adults found[1]
Trap crop:		
Native	49	29
Sterile	48	22
Farmer cotton:		
Native	39	29
Sterile	33	29

[1] Total of 565 fields in the first buffer zone.

TABLE 6.—*Results of detection surveys for suspect boll weevil oviposition-damaged squares in the first buffer zone in 1973*

Week of—	No. collections[1]	No. damaged squares	No. immatures	No. eggs
June 20	13	200	16	10
27	18	212	25	40
July 4	18	119	23	31
11	34	186	53	38
18	30	256	51	67
25	39	287	87	56
Aug. 1	49	660	181	57
8	29	152	57	34
Total	230	2,072	493	333

[1] Collections made in 136 individual fields.

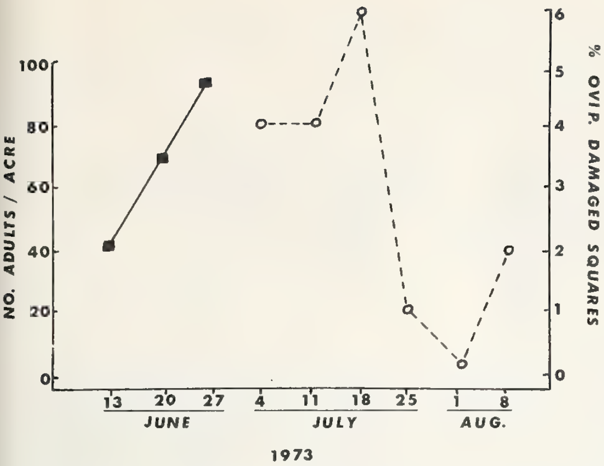

FIGURE 6.—Number of adults per acre and percent boll weevil oviposition-damaged squares in the second buffer zone in 1973.

in early July, oviposition-damaged squares were averaging 4.0% in 95% of the fields. This increased to 6.0% in 94% of the fields by mid-July, at which time 2 applications of azinphosmethyl at 0.25 lb/acre were applied to suppress first generation adults and reduce population buildup. During the remainder of the season, the oviposition-damaged squares ranged from 0.1% to 2.0% and were found in 18% to 55% of the fields.

In summary, there appears to be a definite relationship between the incidence of infested fields and number of boll weevils captured in pheromone traps[4] in the different areas of the eradication zone in 1973. There was an increase in native weevils captured and infested fields as one moved from south to north, with at least 90% of the trapped weevils coming from the units in which the infestations occurred. This incidence of captured weevils and infestations was directly related to the distance from considerable boll weevil infested cotton acreage outside the experimental area. The apparent relationship between these factors and results of a migration study by Cross[5] indicated that boll weevil migration into the eradication zone did occur. Closely considering all possibilities, and given the fact that the 33 fields found infested, comprising 9.0% of the total acreage, were located in the northern one-third of the eradication zone, it is surmised that the majority of the infestations found in 1973 were caused by migrant, gravid females.

[4] See D. D. Hardee, "Development of Boll Weevil Trapping Technology," this volume.

[5] See "Relative Populations and Suggested Long-Range Movements of Boll Weevils Throughout the Area of the Pilot Boll Weevil Eradication Experiment As Indicated by Traps in 1973," this volume.

TRAPPING DURING THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT, 1971-73

By D. D. Hardee and F. J. Boyd[1]

The results of mass-trapping experiments have been discussed to show the justification for including pheromone traps as one of the suppression measures in the Pilot Boll Weevil Eradication Experiment (PBWEE).[2] Two significant improvements since the conclusion of earlier trap experiments which further justified traps as a suppression measure were the development of the non-sticky Leggett trap (Leggett and Cross 1971), and the availability of the synthetic pheromone, grandlure (Tumlinson et al. 1969, Hardee et al. 1974), in slow-release formulations (Bull et al. 1973, Hardee et al. 1974) that are effective in the field for at least 7 days. This paper summarizes the results achieved with all phases of trapping in the PBWEE in 1971-73.

TRAPPING IN 1971–72

Survey traps at the rate of two per field were operated from August 4, 1971, through March 15, 1972 (Cross et al. 1971), and from August 2, 1972, through March 28, 1973 (Leggett and Cross 1971). These traps provided (1) a measure of the effectiveness of in-season and reproduction-diapause control programs in 1971–72, (2) a comparison between population densities in 1971 and 1972, and (3) a measure, along with surface woods trash samples, of winter survival in the 2 years. Based on the summaries presented in table 1, boll weevil populations during the in-season and reproduction-diapause control phases in 1972 were over 98% less than in 1971. Because of the large number of boll weevils captured on traps and the moderate infestation of boll weevils in fields in the spring of 1972 (table 2), the trapping and sterile-male release phases of the experiment in 1972 were terminated in early July. Subsequently, the boll weevil population was subjected to in-season and reproduction-diapause insecticide treatments which reduced the boll weevil population to a very low level. When trap records for zones I and II are compared with each other in 1972 and 1973, and with zone III and untreated areas for 1973 (table 2), the effectiveness of insecticide treatments in reducing the size of the boll weevil population is well documented. This effectiveness is also shown in table 3 for percent egg-punctured squares and adult boll weevils collected in visual surveys for zones I–III for 1971–73 and in table 4 for specific seasons throughout both years.

TABLE 1.—*Number of boll weevils captured on survey traps in PBWEE, August–March 1971–72*

Month	No. boll weevils captured/trap/month in—			
	Zone I		Zone II	
	1971[1]	1972[2]	1971[1]	1972[2]
Aug.	55.9	0.80	31.3	0.46
Sept.	36.5	.26	30.5	.58
Oct.	9.9	.63	15.3	1.15
Nov.	6.8	.16	13.3	.38
Dec.	4.2	.15	8.1	.22
Jan.	1.7	.008	1.4	.018
Feb.	.4	.004	.2	.001
Mar.	5.2	.001	5.9	0
Total	120.6	2.01	106.0	2.82

[1] Wing traps.
[2] Leggett traps.

One cultural measure employed in late 1972 was destruction of stalks after harvest was completed. After stalks were destroyed, the fields were trapped for an additional 2 weeks to cap-

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[2] See Hardee, "Development of Boll Weevil Trapping Technology," this volume.

TABLE 2.—*Number of boll weevils captured with Leggett traps during the growing seasons of 1972–73*

Month	No. boll weevils captured/trap/month in—					
	Zone I		Zone II		Zone III	Untreated
	1972	1973	1972	1973	(1973)	(1973)
Apr.	1.3	0.016	1.1	0.021	1.6	23.4
May	9.3	.100	6.7	.170	31.8	105.8
June	14.2	.290	11.3	.540	36.6	238.7
July	4.2	.085	2.2	.010	4.0	23.2
Aug.	...	.006	...	.005	.4	1.0
No./trap	29.0	0.50	21.3	.84	74.4	492.2
No./acre	53.9	.79	33.9	.80	...	....
Total/ zone	156,580	1,459	132,350	3,954	40,172	....

TABLE 3.—*Egg-punctured squares and adult boll weevils per acre in zones* I–III *in 1971–1973*

Year[1]	Egg-punctured squares in zone (%)			Adult boll weevils/ acre in zone		
	I	II	III	I	II	III
1971	40.3	22.0	34.7	807.0	561.0	435
1972	3.6	4.3	26.5	3.2	7.6	198
1973	.02	.04	5.2	.2	2.4	89

[1] Through week of July 30–August 3 only in 1973. In 1971–72, records are through frost.

TABLE 4.—*Number of boll weevils captured per season in PBWEE*

Zone	No. weevils/trap/week			
	Aug.–Nov. 1971	May–July 1972	Aug.–Nov. 1972	May–July 1973
I	6.4	2.3	0.13	0.04
II	5.2	1.9	.13	.06
III	14.4	...	...	5.53
Untreated	143.7	33.0	130.6	27.66

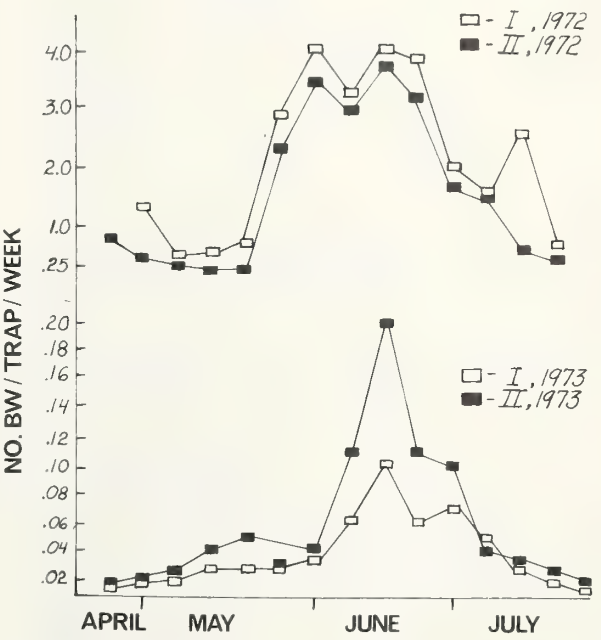

FIGURE 1.—Emergence of boll weevils as measured by trap catches in zones I and II, PBWEE, 1972–73.

ture any boll weevils released from bolls by stalk destruction. The results in the following table show that about four times as many boll weevils were captured between September 25 and October 20 around fields with destroyed stalks than around fields with stalks left standing.

Zone	No. boll weevils/trap around fields	
	Cotton standing	Cotton destroyed
I	0.05	0.2
II	.2	.9

Stalk destruction forced some boll weevils from the destroyed fields and these in turn were captured in traps around the fields.

Seasonal emergence patterns as measured by trap catches are shown for zones I and II in figure 1. The results show that during mid-May in 1972, and during the week of June 11 in both years, peak emergence occurred for both zones. Since traps were checked on a weekly basis, peak emergence actually occurred sometime during the week prior to the date traps were checked.

In tabular form, emergence patterns for zones

TABLE 5.—*Emergence pattern of captured boll weevils by zone, 1973*

Zone	Total No. weevils captured	Accumulative percent of capture by—				
		Apr. 29	May 20	June 10	July 1	Aug. 3
I	1,459	2.4	12.5	33.4	81.6	100.0
II	3,954	1.3	13.8	34.3	86.0	100.0
III	40,172	0.5	15.8	60.5	94.5	100.0
Untreated	4,724	8.5	20.1	66.5	93.8	100.0
Total or mean	50,309	3.2	15.6	48.7	89.0	100.0

TABLE 6.—*Emergence pattern of captured boll weevils by units in zone* I, *1973*

Unit	Total No. weevils captured	Accumulative percent of capture by—				
		Apr. 29	May 20	June 10	July 1	Aug. 3
1	4	25.0	25.0	50.0	100.0	....
2	54	0	1.8	7.4	80.4	100.0
3	146	0	.7	4.1	75.3	100.0
4	971	2.3	13.4	31.2	79.0	100.0
5	214	5.6	20.6	55.6	93.4	100.0
6	70	0	8.6	77.1	91.4	100.0
Mean	1,459	2.4	12.5	33.4	81.6	100.0

TABLE 7.—*Emergence pattern of captured boll weevils by units in zone* II, *1973*

Unit	Total no. weevils captured	Accumulative percent of capture by—				
		Apr. 29	May 20	June 10	July 1	Aug. 3
1	232	0	5.2	13.4	72.8	100.0
2	1,796	.4	9.1	27.7	85.1	100.0
3	1,456	1.5	14.5	34.4	86.1	100.0
4	138	4.3	37.0	72.5	98.6	100.0
5	66	1.5	18.2	33.3	74.2	100.0
6	266	5.6	32.7	72.6	94.0	100.0
Total or mean	3,954	1.3	13.8	34.3	86.0	100.0

I–III and untreated areas in tables 5–7 show that 80%–85% of all emergence occurred after May 20 in 1973. Over two-thirds of the total emergence in zones I and II occurred after June 10, but these results are influenced by trap records around fields planted in 1972 but not in 1973. Data collected by Hardee and Boyd (unpublished) show that overwintered weevils are trapped more readily after July 1 around fields planted the previous season and not planted the current season than around fields planted both seasons. Since over 60% of the total number captured in zone I, i.e., were captured around unplanted fields (table 8), the emergence pattern as a whole was influenced greatly by the response around unplanted fields. These results strongly confirm the value of trapping unplanted fields as was done in the PBWEE. The summary by unit in zone I (table 8) shows that traps around 64% of all planted fields in zone I

TABLE 8.—*Numbers of boll weevils captured in traps around planted and unplanted fields in zone I, 1973*

Unit	No. planted		No. weevils captured at fields			% Planted fields capturing weevils	Percent of total captured at unplanted fields	Percent of total captured in zone
	Fields	Acres	Planted	Unplanted	Total			
1	31	276	3	1	4	9.7	25.0	0.3
2	40	293	22	32	54	60.0	59.3	3.7
3	42	402	80	66	146	66.7	45.2	10.0
4	45	274	287	684	971	100.0	70.4	66.6
5	41	287	170	44	214	80.5	20.6	14.6
6	37	285	20	50	70	54.0	71.4	4.8
Total or mean	236	1,817	582	877	1,459	64.4	60.1	100.0

captured boll weevils, but 60% of the total boll weevils captured occurred around unplanted fields. Unit 4 contributed two-thirds of the total captured, and units 3, 4 and 5 contributed 90% of the total.[3]

Field No. 120 in zone I, unit 4, was not discovered until mid-September of 1972, and received no insecticide prior to that time. Upon discovery the 2-acre field was heavily populated with boll weevils and was immediately treated, trapped, and destroyed. Traps placed around and on lines radiating from this field captured the following numbers of boll weevils in 1973:

Date	No. boll weevils captured	Date	No. boll weevils captured
Apr. 2–15	2	June 11–24	20
Apr. 16–29	18	June 25–July 8	1
Apr. 30–Mar. 13	37	July 9–22	4
Mar. 14–27	54	July 23–Aug. 5	0
May 28–June 10	40	Total	176

Since this field accounted for over 18% of the total number of weevils captured in unit 4 in 1973, and since these numbers are included in those given for unit 4 in previous tables, these figures indicate the potential problem posed by failure to detect even a small field during the reproductive phase of boll weevils.

Table 9 shows the number of fields in zone I in which boll weevils were detected by traps, egg-punctured squares, or by both means. A total of 154 out of 236 fields was found positive for boll weevils by either or both methods. Of these, traps detected boll weevils around 147 fields and boll weevil infestations were detected in 32. In only 7 of the 32 fields did traps fail to capture boll weevils where an infestation developed. Thus, since weevils were captured on traps around 122 of the 154 fields in which no suspect egg-punctured squares were found by the sampling method employed, we can conclude that traps contributed greatly to detection and suppression in the PBWEE. Because the PBWEE was scheduled for termination on August 10, about half of the peripheral Leggett traps were removed during the week of July 23, and the

[3] Boyd, "Boll Weevil Population Levels During the In-Season and Reproduction-Diapause Control Phases of the Pilot Boll Weevil Eradication Experiment," this volume.

remainder was removed during the week of July 30. For this reason trap catches from July 30 to August 3 are for only half the previous complement of traps. There were no trap records during the week of August 4–10, the last week of the experiment. As part of a series of studies in which we were evaluating the effectiveness of the in-field trap principle, in-field traps were placed in 4 fields in each of zones I and II. (See Mitchell and Hardee 1974 for details.) Therefore, during the week of August 4–10, only four fields (three of which were previously infected and on insecticide schedule) were trapped in zone I of the PBWEE; that is, trapping was carried on in the four fields in unit 4 which contained the in-field traps. The results below show the value of in-field traps in detecting low-level populations of boll weevils:

Zone	Fields	Surveys (fields × weeks)	Positive surveys			
			Traps	Visual	Traps & visual	Total
I	4	8	4	1	1	6
II	4	36	22	1	2	25
Total..	8	44	26	2	3	31

Sex ratios shown in tables 10–12 indicate that midseason responses are predominantly from females, indicating a true sex-pheromone response, as contrasted to an aggregating response from both sexes in early and late season. The detailed results of in-field trap studies in zone I (table 12) and zone II (table 13) emphasize the value of in-field traps in detecting low-level infestations of boll weevils, and suggest that their proper use under these conditions represents a powerful tool in suppression and elimination. For example, in field 156, zone II (table 13), no egg-punctured squares were detected from a sample of 600 total squares taken at random during the weeks of July 23, July 30, and August 6. During these same weeks, however, 14, 47, and 73 boll weevils were captured, respectively, in in-field traps, all but 2 of which were females. All of the results with in-field traps illustrate a point which most cotton entomologists recognized for some time: the difficulty encountered in measuring accurately extremely low levels of boll weevils by visual surveys. To emphasize the value of in-field traps in improving our methods of detection, a series of hypothetical calculations

TABLE 9.—*Measure of role of Leggett traps in detection and suppression in zone* I, *1973*

Unit	No. planted fields	No. fields positive			
		Traps only	Oviposition-puncture only	Both methods simultaneously	Total
1	31	3	0	0	3
2	40	24	0	0	24
3	42	23	1	4	28
4	45	25	2	18	45
5	41	30	4	3	37
6	37	17	0	0	17
Total	236	122	7	25	154

TABLE 10.—*Capture of boll weevils in in-field traps in zones* I *and* II

Zone	Boll weevils captured in—					
	June		July[1]		Aug.[2]	
	No.	Fields (%)	No.	Fields (%)	No.	Fields (%)
I	....	....	21	90.5	10	80.0
II	31	74.2	103	96.1	89	98.9
Total or mean	31	74.2	124	95.2	99	97.0

[1] Week of July 28–Aug. 3.
[2] Week of Aug. 4–10.

TABLE 11.—*Infestation and trap records in selected fields (zone I, unit 4, PBWEE) containing in-field traps*

Field		No. Leggett traps[1]	Weevils captured in Leggett traps	Infestation record		Date insecticide applied	In-field traps[1]		
								No. weevils captured	
No.	Acres			Week of—	Weevil form observed		No. in field	July 30	Aug. 6
16	1	3	[2]2	......	None	None	12	0	1 N ♂
17	6	6	0	July 2 July 9 July 16 Aug. 6	Egg-punct. sq. Egg-punct. sq. Egg-punct. sq. Egg-punct. sq.	July 18, 24, 27; Aug. 3.	8	0	0
23	4	5	[3]4	July 9 July 16 July 23	Egg-punct. sq., larvae. Larvae Larvae	July 12, 16, 20, 23, 27, 30; Aug. 3, 6.	16	2 N ♂, 13 N ♀	1 N ♂, 4 N ♀
41	5	3	0	July 16 July 23 July 30	Larvae Egg-punct. sq. Egg-punct. sq.	June 27[4]	16	6 N ♀, 1 E ♂, 1 E ♀	4 N ♀, 1 E ♂

[1] Because of budgetary limitations, about 1/2 of the total number of Leggett traps was operated during the week of July 30; none was operated during the week of Aug. 6. N = native; E = ebony (laboratory reared).

[2] 1 ♂ on June 25; 1 ♂ on July 2.

[3] 1 ♂, 1 ♀ on June 12; 1 ♂, 1 ♀ on June 25.

[4] Dates of additional applications were misplaced.

TABLE 12.—*Capture of boll weevils in in-field traps in a low infestation area (zone II, Covington County)*

Week of—	No. native weevils captured in field[1]											
	[2]156 (10 traps/acre)			157 (5 traps/acre)			62 (5 traps/acre)			165 (10 traps/acre)		
	M	F	No./acre or % infest.[3]	M	F	No./acre or % infest.[3]	M	F	No./acre or % infest.[3]	M	F	No./acre or % infest.[3]
June 11	0	2	0	0	1	0	0	0	0	0	0	0
18	4	7	0	1	1	0	0	1	0	1	0	0
25	0	5	0	0	1	0	0	1	0	2	4	0
July 3	0	8	0	0	0	4	0	0	0	0	0	0
9	0	1	0	0	0	0	0	1	0	0	1	0
16	1	12	0.5	0	1	0	0	1	0	0	0	0
23	0	14	0	0	1	0	0	0	0	0	0	0
30	2	45	0	1	13	2	0	0	0	0	1	0
Aug. 6	0	73	0	1	15	0	0	0	0	0	0	0

[1] M = male, F = female.

[2] Field 156 received insecticide applications on June 8, July 19, 24, 31, and Aug. 8. None of the other 3 fields was treated. Fields 156 and 157 were planted May 1; fields 62 and 165 were planted June 7–9. 1 ♀ was captured on May 14 in 2 Leggett traps in field 156; 1 ♂ on June 4, 1 ♀ on June 25 in Leggett traps in field 156; fields 62 and 157 had no Leggett traps.

[3] No weevils were detected in row counts averaging 400 feet weekly. All data given are percent egg-punctured squares of the 300–600 squares examined weekly.

were made pertaining to sampling in the PBWEE.

The following assumptions were made before the calculations were attempted: (1) Two boll weevils per acre of cotton survived the winter. Early suppression measures (traps, trap crops, insecticide application at pinhead square stage) reduced this level 90%. Therefore, 1 week after pinhead squaring, there were two boll weevils per 10 acres of cotton (1 male, 1 female). (2) Two boll weevils per 10 acres will produce about 0.01% infestation (Lloyd and Merkl 1966). (3) To detect a 1% infestation, 500 squares must be sampled (Lincoln et al. 1963); therefore, to approach 100% efficiency in detecting a 0.01% infestation, at least 50,000 squares should be sampled. (4) An overwintered female will lay about 150 eggs (E. P. Lloyd, unpublished data). (5) Squaring rate = 20,000 per acre 1 week after 1/3-grown squares, peaks at 200,000 per acre in 4 weeks, holds this level for 3 weeks, and then declines (Lincoln et al. 1963). (6) Animal and Plant Health Inspection Service operations in PBWEE sampled at random at least 200 to 400 squares (up to 1,000 in some cases) off plants in the largest cotton per 10-acre count or less.[4]

Based on the above assumptions and utilizing Poisson distribution functions (Fisher and Yates 1957), we can calculate the following:

Weeks after 1/3-grown square	No. squares/ 10 acres	No. egg-punctured squares/ 10 acres
1	200,000	40
2	600,000	60
3	1,200,000	60
4	2,000,000	20
	Punctured squares (%)	Prob. of detecting 1 punctured square in 400
1	0.02	0.077
2	.01	.039
3	.005	.020
4	.001	.004

Therefore, 1 week after ⅓-grown square, with random sampling we had 8 chances in 100 of de-

[4] Boyd, "Operational Plan and Execution of the Pilot Boll Weevil Eradication Experiment," this volume.

tecting, in any field, 1 egg-punctured square in a sample of 400, given the above assumptions. In any field of less than 10 acres the chances would be improved but where populations are less than two weevils per 10 acres, as the season progresses (and number of squares per acre increases), the chances decrease drastically to approximately four in 1,000 at peak squaring. Based on these assumptions and calculations, the results as shown in tables 10–12 emphasize that in-field traps should be considered as one of the measures to be used in detection, management, suppression, and elimination of the boll weevil in any future program.

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EVALUATION OF A TRAP CROP SYSTEM FOR BOLL WEEVIL SUPPRESSION

By F. R. Gilliland,[1] Jr., W. R. Lambert,[2] and R. L. Davis[2]

The Pilot Boll Weevil Eradication Experiment (PBWEE) was designed to test the technological feasibility of various boll weevil suppression techniques for use in an eradication attempt across the Cotton Belt. Two population-suppression techniques employed in the PBWEE were aldicarb-treated, early-planted trap crops baited with grandlure, the synthetic boll weevil aggregating pheromone (Hardee et al. 1972), and grandlure-baited Leggett traps (Leggett and Cross 1971) placed around the periphery of cottonfields (Boyd 1973).

Earlier work with grandlure-baited traps and grandlure-baited trap crops in the PBWEE (Boyd 1973, Gilliland et al. 1973) indicated that these suppression techniques would be vital in achieving success in a boll weevil eradication program. The work of other contemporary researchers with trap crops (Bradley 1967), and grandlure-baited traps (Hardee et al. 1969, 1970, 1971, 1972), or combinations of the two (Lloyd et al. 1972, Scott et al. 1974) has also indicated, however, that these boll weevil suppression techniques have great potential for use in cotton insect pest management programs. Thus, experiments were designed and conducted during 1973 to define further the role of grandlure traps and grandlure-baited trap crops in a boll weevil suppression program.

PROCEDURES

Three study areas were selected in Macon County, Ala. The trap crops consisted of four rows of cotton planted 1 to 6 weeks prior to the remainder of the field. Aldicarb was applied in-furrow at 1.0 lb active ingredient/acre at planting, and as a sidedress at 2.0 lb active ingredient/acre at the pinhead square stage. Grandlure-baited Leggett traps were erected around the periphery of the fields at a density of about one trap/per acre. All traps were serviced weekly from early May through late June. Grandlure bait stations were established at 100-ft intervals in the trap crops 2 weeks prior to squaring. The bait stations consisted of a shell vial containing a grandlure-impregnated wick attached to a wire stake that held the bait about 18 inches above the drill of one row of the trap crop. The bait stations were renewed with fresh grandlure at weekly intervals throughout the summer.

In addition to the complete system of trap crops, traps, and bait stations, various combinations of these components were tested to measure the value of each. Representative fields in three different areas were selected as test sites (table 1). At the Marvyn location, 15 small fields (4–10 acres) were selected to test 5 treatment combinations. In these fields the trap crops were planted 3 to 4 weeks prior to the remainder

TABLE 1.—*Treatments in trap crop evaluation experiment, Macon County, Ala., 1973*

Location	Treatments No.	Treatments Description[1]	No. trap crop fields
Marvyn	1	TC+BS	1
Do	2	T+TC(w/o Aldicarb)+BS	1
Do	3	T	0
Do	4	T+TC	1
Do	5	T+TC+BS	1
Little Texas	1	TC+BS	1
Do	2	T+TC	1
Do	3	T+TC+BS	1
Shorter	1	T+TC+BS	2

[1] T=Grandlure-baited Leggett traps. TC=Aldicarb-treated trap crop. BS=Grandlure bait stations.

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of the field. At Little Texas, three treatment combinations were tested in nine fields (10–25 acres). All trap crops at Little Texas were planted about 2 weeks prior to the remainder of the field. The third location, Shorter, was an area of relatively large fields. Here three fields (25–60 acres) were selected to test the complete suppression system. These fields had been treated with a four-application diapause control program during the fall of 1972. Because of adverse weather, trap crops at Shorter had to be replanted only one week prior to the remainder of the fields. At both Little Texas and Shorter, fields of 25 acres or more had two trap crops. In all other fields only one trap crop was planted.

Effectiveness of the various treatment combinations was assessed by several methods, but particularly by whole-plant examinations. Whole-plant counts were made by examining all plants in a 5-ft section of row. The number of such counts varied according to field size: in fields less than 10 acres, there were 10 counts in both trap crop and regular crop; 10–20 acres, 15 counts; 20–30 acres, 20 counts; 30 or more acres, 30 counts. Sampling was initiated May 30 and continued on a weekly basis until crop maturity in mid-September, or until regular applications of insecticides were begun.

RESULTS AND DISCUSSION

Trap crops at the Marvyn location were successfully established. In most instances the planting date for the trap crop was about 1 month earlier than the main planting. The trap crops came to good stands, and considerable difference in size between the trap crop and the rest of the field was apparent until midseason. At Little Texas and Shorter, however, the trap crops were not as good. At Little Texas, very poor stands were achieved in the trap crops. Despite a 2-week difference in planting dates, the regularly planted cotton outgrew the trap crops; by late June the regularly planted crop was taller and fruiting more heavily than cotton in the trap crops. At Shorter, first stands in the trap crops were inadequate and required replanting only 1 week prior to the planting date for the regular crop. Thus, as at Little Texas, the trap crops at Shorter had little size or maturity advantage.

Records of boll weevil capture in Leggett traps at Marvyn show little differences between treatments until peak emergence occurred in early June (table 2). During this period of peak emergence, trap catches around fields that had no trap crops increased greatly. Thereafter, the decline in trap catches around all fields was similar, and by late June trap catches were quite low. At Little Texas, no differences were noted in trap catches among the various treatments. At Shorter, trap catches indicated a much lower overwintered weevil population than at Marvyn or Little Texas. This lower population probably can be attributed to the diapause control treatments applied to the Shorter fields during the fall of 1972.

The trap crops planted at the Marvyn location were very effective in attracting overwintered weevils that escaped the Leggett traps and entered the fields (table 3). Once weevils entered the trap crops, they did not appear to leave and move into the regularly planted cotton. The effectiveness of the trap crops in attracting overwintered weevils is indicated by the difference in weevil populations in the regularly planted cotton in the various treatments at Marvyn. In Treatment 3, where trap crops were not planted, weevil populations in the regularly planted crop prior to July were considerably higher than in fields containing a trap crop. Subsequent to the June 14 sidedress application of aldicarb, weevil populations in the trap crops at Marvyn were reduced appreciably. The degree of suppression by the aldicarb sidedress is apparent upon comparison of populations in the various treatments. Populations in the trap crops of Treatment 2, which did not receive either the in-furrow or sidedress application of aldicarb, did not decrease during June or July. An explanation for the failure of weevil populations to increase in the regularly planted portions of these fields during the remainder of the test is not readily apparent.

Trap crops at Little Texas and Shorter were not as effective as those at Marvyn. Although overwintered weevil populations were higher in the trap crops than in the regularly planted portions of the fields during early June, these differences were not apparent by late June. Following the aldicarb sidedress on June 14–15, weevil populations in the trap crops were reduced and, in most instances, remained low until after F_2 emergence in late July. However, weevil populations in the regularly planted crop ob-

TABLE 2.—*Boll weevils captured in grandlure-baited Leggett traps around fields used for various treatments in trap crop evaluation experiment, Macon County, Ala., 1973*

Location	Treatment No.[1]	Weevils/trap								
		May					June			
		4	10	17	26	30	6	13	20	26
Marvyn	1	..	..	..	..	..	..	..	..	..
Do	2	8	20	12	24	18	19	14	6	1
Do	3	6	20	8	23	26	56	22	14	3
Do	4	6	15	12	22	20	25	10	9	2
Do	5	4	11	6	16	15	18	10	7	1
Little Texas	1	..	..	..	..	..	..	..	..	..
Do	2	6	20	7	20	27	28	29	7	1
Do	3	8	22	8	24	18	26	33	7	1
Shorter	1	3	8	5	10	14	9	15	3	1

[1] See table 1, note 1, for description of treatments.

TABLE 3.—*Summary of boll weevil populations in various treatments of trap crop evaluation experiment, Macon County, Ala., 1973*

Location	Treatment No.[1]	Avg. weevils/acre			
		Pre-sidedress[2]		Post-sidedress[3]	
		Trap crop	Reg.	Trap crop	Reg.
Marvyn	1	1,502	29	975	65
Do	2	896	0	1,018	65
Do	3	....	174	....	87
Do	4	866	0	542	22
Do	5	1,473	87	455	0
Little Texas	1	838	116	412	477
Do	2	799	260	282	499
Do	3	1,581	159	439	379
Shorter	1	501	163	130	209

[1] See table 1, note 1, for description of treatments.
[2] May 30–June 14. Reg.=Regularly planted portion of fields.
[3] June 14–July 15. Reg.=Regularly planted portion of fields.

viously were not affected by the aldicarb sidedress and reached relatively high levels before sampling was terminated. The relatively poor quality of the trap crops, in terms of stand and differential height and maturity, at the Little Texas and Shorter locations undoubtedly contributed greatly to the ineffectiveness of the trap crops at these locations. Also, at Shorter, the maximum number of trap crops planted per field was two, even though the fields were much larger than those at Marvyn (table 1). It is likely that an increased number of trap crops in these larger fields would have provided more positive results.

The importance of achieving a good height and maturity differential to optimize trap crop effectiveness is demonstrated by a comparison of weevil populations occurring from June 1 until July 27 in the trap crops and regular crops of a test treatment common to all locations (table 4). The great difference in weevil infestation occurred at the Marvyn location where the average difference in planting dates for trap crops and regular crops was 4 weeks. The most ineffective trap crops were at Shorter where there was only a 1 week difference in planting dates.

Grandlure bait stations contributed to the effectiveness of trap crops. Accumulative estimates of total weevil populations occurring in trap crops at Marvyn indicate the value of bait stations (table 5). Trap crops with grandlure bait stations attracted appreciably more weevils than trap crops without bait stations. A further indication of the attractiveness of the bait sta-

TABLE 4.—*Effectiveness of trap crops for attracting boll weevils in three situations*

Location and treatment[1]	Total weevils/acre[2] Trap crop	Reg.	Trap crop: reg. ratio	Avg. planting interval, trap crop–reg. (weeks)
Marvyn,				
T+TC+BS	7,887	260	30.3:1	4
Little Texas,				
T+TC+BS	7,799	3,487	2.25:1	2
Shorter,				
T+TC+BS	2,341	3,176	.75:1	1

[1] See table 1, note 1, for description of treatments.
[2] Includes data from May 31–July 27. Reg.=Regularly planted portion of fields.

TABLE 5.—*Boll weevil populations in trap crops with and without grandlure bait stations, Macon, County, Ala., 1973*

Treatment[1]	Total weevils/acre, May 30–July 18
1. TC+BS	9,447
2. T+TC(w/o aldicarb)+BS	7,887
3. T	.....
4. T+TC	3,986
5. T+TC+BS	7,887

[1] See table 1, note 1, for description of treatments.

TABLE 6.—*Initial boll weevil population increases above economic threshold in regularly planted portions of fields, Macon County, Ala., 1973*

Treatment[1]	Initial date ET exceeded[2] 300+weevils/acre	10% Ovip.-punct. squares
1. Regular crop	July 27	July 31
2. Regular crop	Aug. 9	Aug. 14
3. Regular crop	June 6	July 10
4. Regular crop	([3])	([3])
5. Regular crop	Sept. 5	([3])

[1] See table 1, note 1, for description of treatments. Treatment at Marvyn location.
[2] Economic threshold=Early season, 250–300 weevils/acre; midseason, 10% oviposition-punctured squares.
[3] Economic threshold never reached.

tions were observations that almost all weevils found in baited trap crops were found within 5 feet of a bait station.

Counts of boll weevil punctured squares (table 6) confirmed the above description of the relative effectiveness of trap crops. At Marvyn, trap crops were very effective in protecting the remainder of the fields from weevil damage. Weevil damage did not reach economic levels in any regularly planted portions of fields containing trap crops until August. At Little Texas and Shorter, however, infestations reached economically important levels much earlier.

In general, this experiment confirmed results obtained in a similar experiment conducted in 1972 (Gilliland et al. 1973). That is, trap crops offer considerable potential as a boll weevil suppression technique. The primary problem of implementing the trap crop system tested is the difficulty of successfully planting trap crops at least 2 weeks before the remainder of the field. Most producers are reluctant to delay their planting operation in this manner. However, the data indicate that the trap crops should be planted much earlier than the regular crop if optimum results are to be achieved. In a well controlled and organized suppression program, eradication program or both, it may be possible to accomplish the necessary differential in planting dates. However, the necessity for early planting of trap crops probably will inhibit wide acceptance and usage of a trap-crop system by individual growers. Hopefully, additional research may produce methods of trap cropping that will negate the necessity of early planting. For example, it may be possible to create a trap crop in a regularly planted portion of a field by the efficient use of grandlure bait stations alone. These baited portions could be treated with systemic or foliar-applied insecticides to kill weevils attracted by the grandlure.

ACKNOWLEDGMENT

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RELEASE OF STERILE MALE BOLL WEEVILS IN THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT IN 1972-73

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The release of sterile male boll weevils was the most complex of the suppression measures employed in the Pilot Boll Weevil Eradication Experiment (PBWEE). Boll weevils for release were reared in a specially designed rearing facility, under carefully controlled conditions, and fed an adult diet medicated with the chemosterilant busulfan, or busulfan + hempa. If the weevils ingest 30.3 ± 2.3 μg of busulfan, excellent sterility is obtained. However, a number of factors can influence the feeding rate and thereby reduce sterility. Variability in feeding can result from microbial contamination in the larval and adult diets, or from fluctuations in temperature and humidity in holding chambers. Lack of uniformity in incorporation of the chemosterilant(s) into the adult diet, and perhaps most important, the inherent turnover of temporary personnel in the mass-rearing laboratory influence final weevil sterility.

The most accurate assessment of the sterility of males is obtained by mating them with virgin females and measuring egg hatch and larval development for a period of 3 weeks. Unfortunately, this is not a practical quality control procedure to use in a release program since it is "after the fact," or "too late." Therefore, a reliable method was developed whereby sterility could be assayed prior to the release of the sterile males in the field. The test devised is referred to as a locomotor activity test. A highly significant (0.99 level) correlation existed between 0- to 24-hour posttreated weevils and 21-day sterility of male weevils when based on 21-day dissection of testes.[2] While there was occasional disagreement between locomotor tests and detailed measurements of sterility, overall the correlation between the locomotor test and laboratory sterility studies was good.

Laboratory quality control tests of sterile male boll weevils were conducted by personnel of both the Boll Weevil Research Laboratory (BWRL) and the Baton Rouge Cotton Insects Research Laboratory (BRCIRL). Since procedures and assessment of the sterility of released weevils were somewhat different, each will be described separately.

BRCIRL procedures—Representative samples of treated weevils were isolated daily at the Robert T. Gast Rearing Laboratory and shipped to Baton Rouge, La., via plane or bus. Groups of 100 to 300 males were fed squares at 30° C; 50 males were allowed to mate overnight with 50 normal virgin females within 7 days after termination of treatment; 100 eggs from each group were implanted in the larval diet. After mating, the sexes were separated and the female weevils were saved for a second mating with surviving males on the 14th day after treatment. Sterility in males at 7 and 14 days was determined from the percentage of eggs that failed to develop into normal adults. Sterility on the 21st day ("permanent sterility") was based on the percentage of survivors with atrophied testes. Some selected matings were also made on the 21st day to confirm the fact that weevils with atrophied testes were sterile.

BWRL quality control procedures—Random

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[2] Wiygul, Glenn, and Haynes, Jack. 1974. A standard locomotor test for the prediction of sterility in boll weevils. Entomol. Exp. Appl. 17: 452–453.

lots of sterilized weevils were obtained twice each week from the Robert T. Gast Rearing Laboratory. Each sample of 100 weevils was subdivided into two groups. All samples were fed fresh squares daily and held at 30±1° C. Half of each biweekly sample was continuously mated with 50 virgin female weevils. Egg hatch and adult emergence were observed weekly for 3 weeks posttreatment. Male sterility was determined by the percentage of eggs failing to develop into normal adults and by dissection of surviving males at 21 days posttreatment. The possibility exists whereby a normal male missexed as a virgin female would be at liberty to mate with the females. Since sterile males became aspermic after 7±3 matings (Haynes, unpublished data), normal missexed males would influence fertility of any females with which they mated. Since neither sterile males nor virgin females were marked, it is impossible to know whether any missexed females existed in any of the weekly matings.

More importantly, continuous matings made it possible to show that a sterile male could have recovered fertility, mated, and died between weekly matings, had the test been so conducted. The fertile sperm from partially or fully recovered males would result in higher egg hatch and emergence among those females with which they mated. Thus, when the males are isolated and allowed to mate only once weekly, the possibility certainly exists whereby one or more males may recover and die before the next mating without the recovery of fertility being detected. The sterile males in the other sublot were not mated, but held on squares for 14 days posttreatment, after which sterility was determined by presence or absence of sperm bundles in the testes.

The differences in quality control techniques between the BRCIRL and the BWRL exist because each laboratory emphasized different aspects in the measurement of male sterility. The BRCIRL emphasized preventing sperm depletion of the sterilized males by confining virgin female weevils with them for 24 hours only twice, within 7 days and at 14 days after sterilization. Virgin females were then removed to minimize the probability of depleting sterile sperm from the sterile males by repeated matings. "Permanent" sterility was based on testicular examination for spermatogenesis 21 days after sterilization. In the BWRL quality control experiments, emphasis was placed on continuously measuring fertility of the sterilized males. Virgin female weevils were placed in the cages with the sterilized males for 21 days. If fertility was regained by males, it would be detected even when the weevils died before the next assay of sterility. "Permanent" sterility also was based on testicular examination of survivors at 21 days after sterilization. While it is obvious that there is not agreement on quality control procedures by the two laboratories, each complements the procedures of the other.

The level of the chemosterilant, busulfan, in the adult diet fed to the mass-reared boll weevils was maintained between 0.08% and 0.14% of the fresh diet during the release period for 1973. Frazier et al.[3] analyzed a total of 241 samples of diet by gas chromatograph according to the method of Sukkestad et al.[4] Of these, 192 (80%) were within the acceptable range. Those batches of diet not within acceptable limits were discarded before being fed.

In the first two field releases, sterile males were released regardless of the outcome of locomotor tests. However, since some of these locomotor tests indicated sterility was of the order of 85% or less, several adjustments were made to insure weevils of high sterility for release. (Data collected subsequently at the BWRL indicated weevils released on or about May 31 and June 4 were 78% sterile by 21 days posttreatment.) Prior to release, sterile males had to be 95% sterile according to the locomotor assay. If weevils were considered to have less than 95% sterility, they were fed an additional day on the busulfan adult diet before being released. Detailed laboratory quality control data measuring sterility was collected to evaluate the accuracy of the locomotive tests in predicting sterility (see table 1).

The above laboratory sterility assays were performed by personnel at the BWRL and the BRCIRL. Sterility assays performed at the BRCIRL indicated male sterility was higher

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TABLE 1.—*Laboratory assays of sterility of boll weevils released on the indicated dates in PBWEE, 1973*

Release periods	Locomotor test score	Avg. percent sterility			
		BWRL assay[1]		BRCIRL assay[2]	
		2 weeks	3 weeks	1 week	3 weeks
May 31–June 11	90	93	82	98.8	88.7
June 14–July 5	92	98	[3]94	99.9	95.2
July 9–21	91	90	83	100.0	98.0
Aug. 2–6	93	100	93	100.0	98.8

[1] Based on 14th-day adult emergence and 21st-day examination of testes.

[2] 1 week, adult emergence; 21st-day examination of testes.

[3] 100% sterility in 5 of 7 samples.

than indicated by BWRL data.

Samples were taken daily by the Baton Rouge Laboratory and twice weekly at the BWRL. This decreased sampling frequency could result in greater variability in the average sterility obtained at the BWRL.

Before July 20, males were sterilized with 0.09% concentration of busulfan in the adult diet. After July 20, 0.09% busulfan + 0.4% hempa were combined in adult diet to improve sterility of both males and females. Sterility was improved, based on laboratory bioassays and field data. However, the combination of chemosterilants increased mortality as shown in table 2.

The lower sterility and greater longevity of released weevils (as indicated by BWRL quality control data and post-experiment field observations) during the last 2 weeks of the experiment is believed to be a reflection of lower morale of temporary personnel in the mass-rearing facility as the PBWEE ended, since the fact that they knew they were going to be terminated could well have influenced the efficiency of personnel.

TABLE 2.—*Laboratory mortality of sterilized boll weevils released on indicated dates in PBWEE, 1973*

Sampling periods[1]	Avg. percent mortality after sterilization (BWRL)		
	1 week	2 weeks	3 weeks
May 31–June 11	45	59	68
June 14–July 5	54	69	84
July 9–27	57	72	81
Aug. 2– 8	39	56	68

[1] Samples were taken 1 day prior to release of weevils.

When the various laboratory assays are compared with field sterility data from the eradication area, there is generally a good correlation except where obscured by migration.

Sterile males were released in 1972 and 1973. Native boll weevil populations in the eradication and first buffer zones in 1972 were too large to suppress by releasing sterile male boll weevils. In early July, the decision was made to suppress the boll weevil population with repeated insecticide treatments for the remainder of the 1972 crop season. While sterile males were released in some fields during 1972, the evaluation of the effectiveness of the sterile releases were confused by the insecticide treatments in 1972. Therefore, evaluation of the effectiveness of the sterile-male releases is based on data collected in 1973. Because adequate numbers of sterile males were not available for release in all fields in the eradication and first buffer zones in 1973, release rates and location of releases were modified to make the most effective use of available sterile males.

The rate of release of sterile males in the eradication zone was 100 per acre per week except for the week of June 20. During the week of June 20, 35 to 50 sterile males per acre were released in the eradication zone. During some weeks, a few fields in the eradication zone received only 50 sterile males per week.

The first 5 mi of the first buffer zone, which adjoined the eradication zone, received releases of sterile males at the rate of 20 to 100 per acre per week depending upon the availability of sterile males. In some weeks, releases were made beyond the 5-mi inner part of the first buffer zone as availability of sterile male weevils permitted. When sterile males were not available for release in fields in the first buffer zone, and infestations were detected, insecticide treatments were applied to these fields to suppress the boll weevil populations. These procedures were necessary to make maximum use of the available sterile males and insure adequate releases in the eradication zone. They represent a compromise from the original plan, which called for a release of 100 sterile males per acre per week in the eradication and first buffer zones from June 4 to August 10.

Effectiveness of Sterile Releases in the Eradication Area.—Data on the effectiveness of sterile releases were confused by the migration of mated native female weevils into the northern part of the eradication zone—which comprised approximately 80% of the acreage. Therefore, in the discussion which follows, the area subjected to sustained migration will be referred to as the northern one-third of the eradication zone (66 fields). The area where migration had little, if any, measurable effect on sterility will be referred to as the southern two-thirds (170 fields) of the eradication zone. The boundary between the northern one-third and southern two-thirds of the eradication zone is an east-west line three-fourths mi south of Jefferson Davis-Marion County boundary (northernmost part of Marion County).

As stated earlier, there was excellent agreement between laboratory assays and field sterility data until after July 9, when migration reduced the percentage of sterility in some fields. As shown in table 3, male sterility ranged from 93% to 95% 3 weeks after the releases in the eradication zone as measured by several assays from June 18 to July 6.

As described earlier, boll weevils were initially fed adult diet containing 0.09% busulfan. From June 14 to June 19, limited egg deposition occurred in the extreme southern part of the eradication zone (unit 1, fields 43 and 45) more than 11 mi from the nearest location where a native boll weevil had been collected in a Leggett trap.

TABLE 3.—*Laboratory assays of sterility of boll weevils released June 18–July 6, 1973, PBWEE*

Laboratory	Percent sterility based on			
	Adult emergence		Testes examination	
	14 days	21 days	14 days	21 days
BWRL	95	94	99	93.0
BRCIRL	99	...	...	95.2

Field observations indicated egg deposition was by several female weevils. Field collections of infested squares from these 2 fields contained 5 larvae and 43 eggs. Eight of these eggs hatched. While none of the larvae were reared to the adult stage for strain identification, it appeared that partially fertile ebony female weevils were released by mistake in these fields. (Larvae were killed when the air conditioning system failed on a weekend.) In order to eliminate these potential infestations in the trap crops (oviposition was entirely in trap crops) they were treated twice a week with azinphosmethyl (0.25 lb/acre) for 3 weeks.

The possibility of egg deposition by accidentally-released, partially sterile ebony female weevils represented a potential source of confusion of evaluation techniques (eggs deposited by native and ebony females confused). Therefore, 0.4% hempa was added to 0.09% busulfan incorporated in the adult diet to improve female sterility as well as to enhance male sterility. This change in chemosterilant procedures began on July 20, 1973.

The northern one-third of the eradication area is compared to the southern two-thirds from June 14 to July 6 in table 4. The lower percent sterility in the southern two-thirds of the eradication area was mostly attributed to presence of five larvae and eight eggs which hatched in unit 1, fields 43 and 45. No native weevils were collected in traps within 10 mi of this location.

In the field, the cotton crop in the eradication area was late and did not begin squaring until the first week in July. By the second week in July, migrant native female weevils had adequate squares for oviposition in nearly all fields in the eradication zone. At this time, the number of larvae in the fields began increasing. However, data on the effective sterility is confused by migration into the northern one-third of the eradication area. If the sterility in the northern one-third (20% of the acreage) of the eradication area is separated from the southern two-thirds, the effect of migration of mated females into the eradication area is shown for the period July 9 to July 27 in table 5.

Laboratory assays indicated sterility had been improved or maintained in most tests after mid-June because of the changes in sterilizing and quality-control procedures. A comparison of laboratory and field assessments of sterility for the

TABLE 4.—*Number of eggs collected, eggs hatched, and larvae, and percent sterility in eradication zone, PBWEE, June 14–July 6, 1973*

Eradication zone	No. fields (acres) with eggs or larvae	No. larvae	No. eggs	No. eggs hatched	Percent sterility
Southern ⅔	16 (120)	7	96	8	85
Northern ⅓	18 (83)	1	123	2	97
Total	34 (203)	8	219	10	93

TABLE 5.—*Number of eggs collected, eggs hatched, and larvae, and percent sterility in eradication zone, PBWEE, July 9–27, 1975*

Eradication zone	No. fields (acres) with eggs or larvae	No. larvae	No. eggs	No. eggs hatched	Percent sterility
Southern ⅔	10 (80)	1	64	0	98.5
Northern ⅓	42 (244)	223	618	24	70.6
Total	52 (324)	224	682	24	72.6

period July 9–27, 1973, is shown in table 6.

Mortality data for sterilized weevils indicated that there was little change in mortality for the two periods, June 14 to July 5 and July 9 to July 27. This would seem to indicate that a fairly uniform rate of sterilization had been achieved. The decrease in effective sterility in the fields in the northern one-third of the eradication zone is a response to the influx of mated native females.

During the final 2 weeks of the Pilot Experiment (July 30–August 10), sterility in the field was much lower than reported in the laboratory quality-control experiments. However, if the sterility in the field is separated into the southern two-thirds and northern one-third the effect of migration of mated native female weevils into the northern one-third of the eradication zone can clearly be seen in table 7.

Of the 12 fields observed to be infested in the northern one-third of the eradication zone during the period July 30 to August 10, only 5 had infestations which had not been identified previously. In searching the fields where infestations had been found previously, infested squares which had fallen to the ground were collected and returned to the laboratory for dissection. Many of these contained third instar larvae or pupae, and had developed from earlier egg deposition in the northern one-third of the eradication zone. With this bias, the sterility in the northern one-third of the eradication zone was calculated to be only 37.5%. However, in the entire southern two-thirds of the eradication zone, only one sterile egg (collected in field 13, unit 5) was detected, and the field sterility was 100% during the final 2 weeks of the experiment.

The laboratory and field assays for sterility are computed in table 8. As in the sampling period of July 9 to July 27, field sterility in the southern two-thirds of the eradication zone during the final 2 weeks of the experiment exceeded the quality-control data reported by the Baton Rouge Laboratory. In the northern one-third of the eradication zone, the effective sterility was obscured by previous migration.

Major improvements in sterilizing and releasing mass-reared sterile boll weevils were made as the PBWEE progressed. The development of the locomotor test as a rapid assay for sterility prior to release, the chemical analysis of chemosterilants in the adult diet, and the use of the ebony strain of boll weevils in the PBWEE made possible the continuous assessment of sterility in the laboratory and in the field as the experiment progressed.

In the PBWEE, the weekly release of 100 sterile males per acre per week maintained a high level of sterility in the released population, since almost 100% of the released males were sterile during the first week after their release. Mortality of 55%, 71%, and 82% after 1, 2, and 3 weeks of release, respectively, eliminated most of the weevils which might have regained fertility. For example, if 100 completely sterile

TABLE 6.—*Laboratory and field assays of sterility in PBWEE, July 9–27, 1973*

Assay method	Percent sterility based on— Field collections	Adult emergence 14 days	Adult emergence 21 days	Testes examination 14 days	Testes examination 21 days
Laboratory:					
BWRL		90.0	86	90	83.0
BRCIRL		99.6	...	...	98.0
Eradication zone:					
Southern ⅔	98.5	...	...	...	...
Northern ⅓	70.6	...	...	...	...

TABLE 7.—*Number of eggs, hatched eggs, and larvae, and percent sterility in field, PBWEE, July 30–August 10, 1973*

Eradication zone	No. fields (acres) with eggs or larvae	No. larvae	No. eggs	No. eggs hatched	Percent sterility
Southern ⅔	1 (10)	0	1	0	100
Northern ⅓	12 (55)	53	67	22	37.5

TABLE 8.—*Laboratory and field assays of sterility in PBWEE, July 30–August 10, 1973*

Assay method	Percent sterility based on— Field collections	Adult emergence 14 days	Adult emergence 21 days	Testes examination 14 days	Testes examination 21 days
Laboratory:					
BWRL		94	72	...	93
BRCIRL		100	...	...	97.5
Eradication zone:					
Southern ⅔	100	...	...	...	...
Northern ⅓	[1]37.5	...	...	...	...

[1] Included ground collections of 3d instar larvae and pupae from fields which were being treated twice weekly with spray of azinphosmethyl. Therefore, this is not an accurate reflection of effective sterility in the fields in the northern one-third of the eradication zone.

males were released each week, and 45% (100% sterile) survived 1 week, 29% (95% sterile) survived 2 weeks, and 18% (85% sterile) survived 3 weeks, effective sterility would be computed as in table 9.

Immediately following a release, effective sterility would be computed at 98%. However, 7 days later, immediately prior to the next weekly release, effective sterility would have dropped to 95%. The sterility of released sterile males during the first week following their release represents the major contribution to the total sterility in the field, especially when mortality is high 1, 2, and 3 weeks after release as in the PBWEE. However, when weekly releases are terminated before the end of the reproduction period (as in the PBWEE), the effective sterility will then be a reflection of the sterility of the surviving released males.

Prior to the end of the PBWEE, 227 adults were reared from larvae collected in fields in the eradication zone. Of these 227 adults, 225 (99.1%) were native weevils. The other 2 (0.9%) were bronze weevils which were both

TABLE 9.—*Theoretical effective sterility in the field when 100 sterile males are released per week with indicated mortality and recovery of fertility*

Week	No. live released males	Percent sterility	No. fertile males
0	100	100	0
1	45	100	0
2	29	95	1.5
3	18	85	3.0
Total	192	98	4.5

reared from larvae collected in field 35 in unit 4. None were ebony weevils.

Following the completion of the PBWEE the long-range dispersal study of Cross[5] showed that native boll weevils began migration into the eradication zone during the week ending August 15. This marked the beginning of the normal late-summer migration of boll weevils. By August 22 substantial numbers of native weevils were captured 15 mi south of the Morgantown, Miss., location. Between August 29 and September 5, 1 native weevil was captured 25 mi south of the Morgantown location.

In-field traps were installed at five randomly selected locations in the eradication zone on August 22, 1973. Native weevils were collected with in-field traps at two of these five locations on August 23, 1973. Ebony weevils were collected at one location (field 43, unit 1). The week of August 30, Leggett and in-field traps were installed around and in 19 additional fields in the eradication zone. Of the 23 trapping locations, native weevils were collected at 8 of them, including field 43 in unit 1. (Time of this collection agrees with the migration pattern established by Cross in his boll weevil dispersal study.) Ebony weevils were collected at 6 of these 23 locations during August 27 to August 31. Bronze weevils (two) were collected at two locations during this same collection period. No other bronze weevils were collected at any of these locations until the week of September 28, with the exception of field 43, unit 1, where the first bronze weevil was collected on September 11.

When all parental matings are considered, the following are the progeny of boll weevil strains which were present in the eradication zone after termination of the PBWEE:

Ebony × ebony=100% ebony.

Ebony × wild=100% bronze.

Ebony × bronze=50% ebony, 50% bronze.

Bronze × bronze=25% ebony, 50% bronze, 25% wild.

Bronze × wild=50% bronze, 50% wild.

Wild × wild=100% wild.

On August 28, six larvae were collected in three fields (unit 1, field 43; unit 2, field 84; and unit 5, field 53) in the eradication zone. These larvae were returned to the BWRL where they were reared to the adult stage for strain identification. Of the six larvae collected, six (100%) were of the ebony strain. These data indicate ebony × ebony parents. There was no evidence that native or bronze weevils had been present at these locations when the PBWEE ended on August 10. Quality control data from the BWRL showed that the sterility of one group of weevils released on August 3 (sampled August 2) was only 60% sterile after 3 weeks (based on adult emergence data). Testicular examinations showed 7% had recovered fertility 3 weeks after sterilization. Mortality after 3 weeks was 43% (corrected by Abbott's formula) in the sample used for quality control. If 2 of the 24 treated weevils which survived regained fertility at 21 days after treatment, it is possible that these 2 fertile males could have mated with a number of the virgin females which would account for the 60% sterility obtained by adult emergence data. Quality control data on sexing by the BWRL indicated that 4% of the weevils released on August 3 were females.

Similarly, adult emergence data (BWRL) for weevils released on August 7 (sampled August 6) indicated 84% sterility after 3 weeks. Testicular examinations of surviving weevils indicated that 7% had regained fertility. There were 14 treated survivors 21 days after treatment. Therefore, one male regained fertility and perhaps mated with more than one of the virgin female weevils, which could account for the lower percentage of sterility based on adult emergence data. These same quality control data indicate that 5% of the weevils released on August 7 were females.

As mentioned earlier, the morale of temporary employees who reared, sexed, and sterilized

[5] Cross, "Relative Populations and Suggested Long-Range Movements of Boll Weevils Throughout the Area of the Pilot Boll Weevil Eradication Experiment As Indicated by Traps in 1973", this volume.

boll weevils, may have dropped as they neared the termination date of their employment and could have detrimentally affected the quality of the sterilized weevils released during the last 10 days of the PBWEE.

With a high degree of effective male sterility during a weekly release program, the accidental release of 1% females will have little if any effect on reproduction because of the high level of effective sterility in the released sterile males.

The absence of ebony adults developing from larval collections during the period of weekly releases clearly indicates that the release of 1% female weevils had no effect on reproduction so long as releases were made weekly. However, measurable ebony populations following the termination of sterile-male releases indicate (1) effective male sterility decreased as releases ended, and (2) the importance of accidently released, partially sterilized females increases when releases are terminated. If releases of sterile males had continued, a high level of effective sterility would likely have continued as well.

RELATIVE POPULATIONS AND SUGGESTED LONG-RANGE MOVEMENTS OF BOLL WEEVILS THROUGHOUT THE AREA OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT AS INDICATED BY TRAPS IN 1973

By W. H. Cross[1]

During 1973, Leggett traps were used extensively for survey of native overwintered and subsequent generations of the boll weevil throughout the area of the Pilot Boll Weevil Eradication Experiment (PBWEE) to indicate relative population levels and long-range movement in the different zones. Trap sites were located in radiating lines at 5-mi intervals from Morgantown, Miss., near the center of the core (zone I). Some changes in trap sites were made during the year. During April, sites were located in zones III, IV, V, and the northeast corner of II. By May 2, 40 sites were established one or more miles from cottonfields and 32, adjacent to 1972 or 1972–73 cottonfields. During May, 27 additional noncottonfield-oriented sites were located in or near zones I and II. Through August 1, these 99 sites each included 10 traps (placed 20 to 35 ft apart in a row) which were checked for weevils and rebaited with grandlure weekly.

After August 1, the number of traps per site was reduced to five, sites in zones IV and V were eliminated, two sites were moved a mile from 1973 cotton, and about eight new sites were added. This resulted in 60 noncottonfield-oriented sites in the revised grid. Then beginning August 22, 29 additional sites were located to 75 mi south of Morgantown along each side of the Pearl River.

During the year, the Animal and Plant Health Inspection Service (APHIS) operated traps around 1972, 1972–73, or 1973 cottonfields as follows: 2,850 in zone I, 4,679 in zone II, and 561 in zone III. Numbers of boll weevils captured per 10 traps and averaged by units in these zones were compared with captures by the above trap sites. Maps were prepared showing the total numbers of boll weevils captured at each site each week beginning April 11. For the purpose of the present report it seems adequate to depict captures for the following more critical periods:

May 16–23 (fig. 1): Emergence of overwintered boll weevils was well advanced, with higher numbers being captured by sites at 1972 cottonfield locations. Small numbers of adults were captured by APHIS traps only in units 3–6 in zone I and units 2–6 in zone II. However, no captures throughout zone I and none in all but the northeast corner of zone II by noncottonfield-oriented traps, suggested little long-range movement into the area by this period.

June 6–13 (fig. 2): A peak in emergence of overwintered weevils was indicated by trap captures, and many noncottonfield-oriented sites in zones III, IV, and V captured large numbers of weevils, suggesting considerable movement away from 1972 fields. Most interesting were the high numbers captured by APHIS traps in north-central zone III and the decreasing gradient of captures into zone I, especially to the south of this highly infested area in zone III.

July 4–11 (fig. 3): Trap captures in all areas were reduced which is typical of this period of the year during reproduction of the boll weevil. Only 5 weevils were captured in zone I and three in zone II by noncottonfield-oriented traps.

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July 25–August 1 (fig. 4): Captures were further reduced at almost every site. Noncottonfield sites in zones I and II were all negative, and APHIS traps indicated only a trace of adult weevils in units 2 and 4 in zone I and units 2 and 3 in zone II.

August 1–8 (fig. 5): Sites in zone I were still negative, but beginning of fall migration was indicated by captures in zone II.

August 15–22 (fig. 6): Considerably increased overall captures and a clear gradient of decreasing captures into the center of zone I suggested long-range movement from outside, especially from north central areas.

September 12–19 (fig. 7): In this week, peak captures occurred during the fall migratory period; a gradient was still evident into the center of zone I of the PBWEE; and movement even south of Morgantown was shown by the newly located line of traps along the Pearl River.

It is concluded that at least most of the adult boll weevils captured by noncottonfield-oriented traps in zone I during June, and again in August, were migrants from outside the area. This is supported by the negative captures before both of these periods, and by the gradient of decreasing captures toward the center of zone I during the periods. Of more interest, however, is the fact that 28 noncottonfield sites in zones I and II captured no weevils during the last week in July, while in the same period, 11 of 38 noncottonfield-oriented sites in zones III, IV, and V captured weevils.

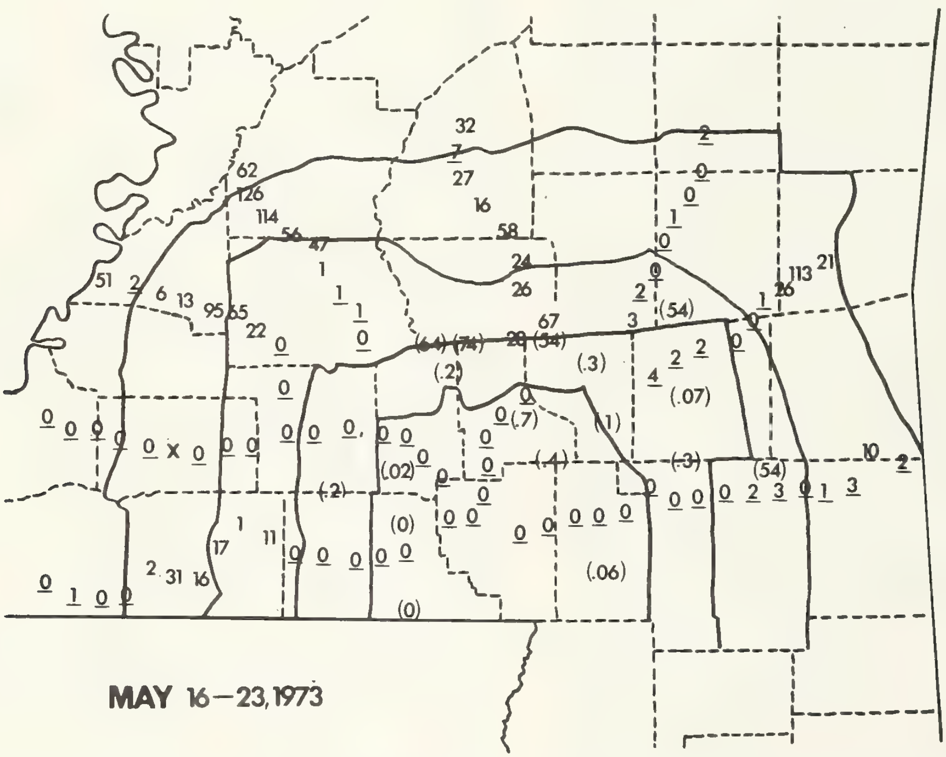

FIGURE 1.—Numbers of boll weevils/10 Leggett traps, May 16–23, 1973. Noncottonfield sites underlined; unit averages in brackets.

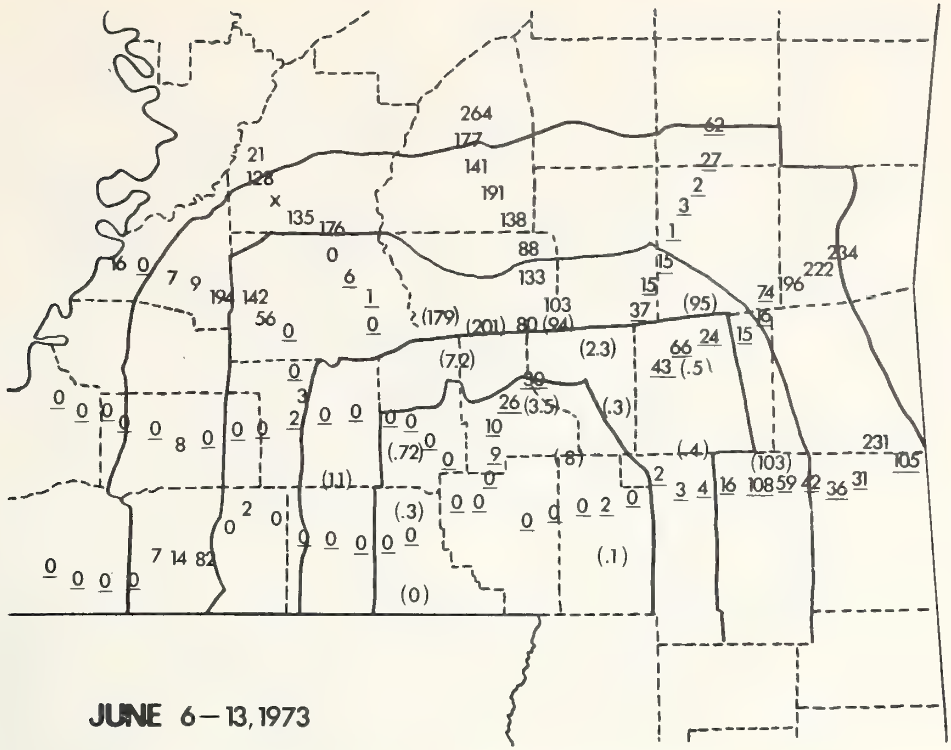

FIGURE 2.—Numbers of boll weevils/10 Leggett traps, June 6–13, 1973. Noncottonfield sites underlined; unit averages in brackets.

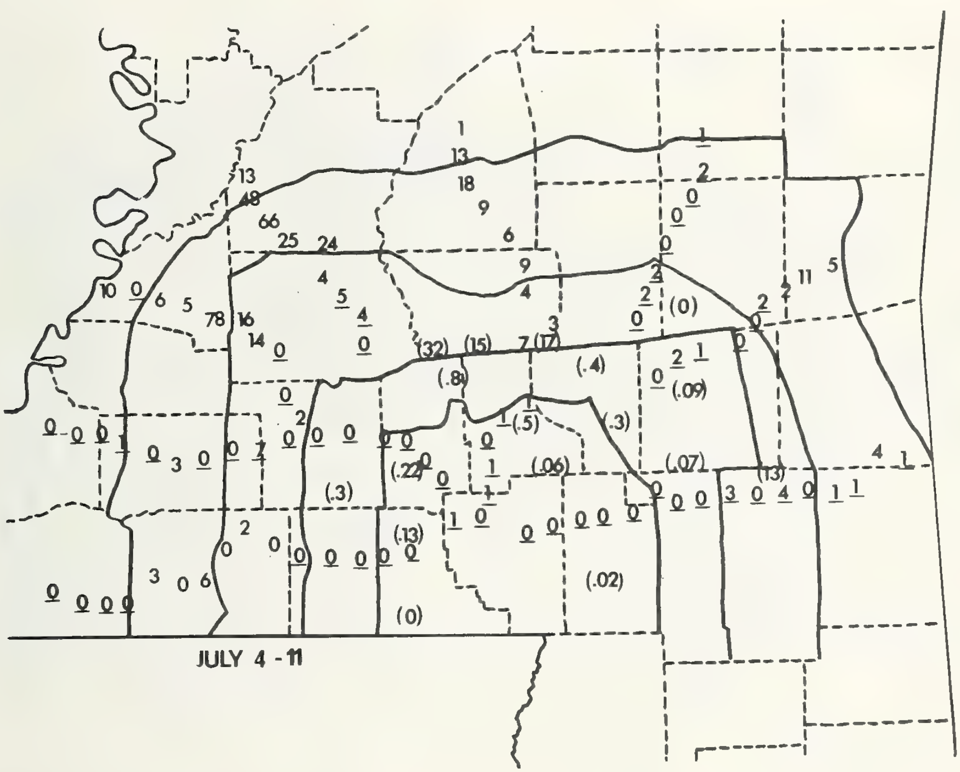

FIGURE 3.—Numbers of boll weevils/10 Leggett traps, July 4–11, 1973. Noncottonfield sites underlined; unit averages in brackets.

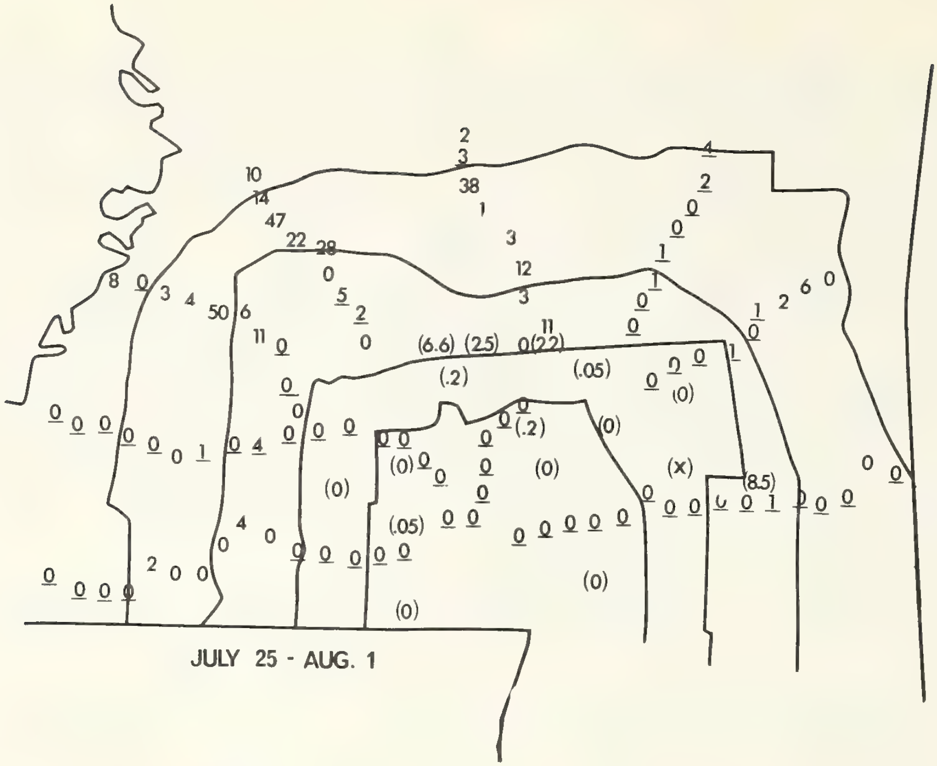

FIGURE 4.—Numbers of boll weevils/10 Leggett traps, July 25–Aug. 1, 1973. Noncottonfield sites underlined; unit averages in brackets.

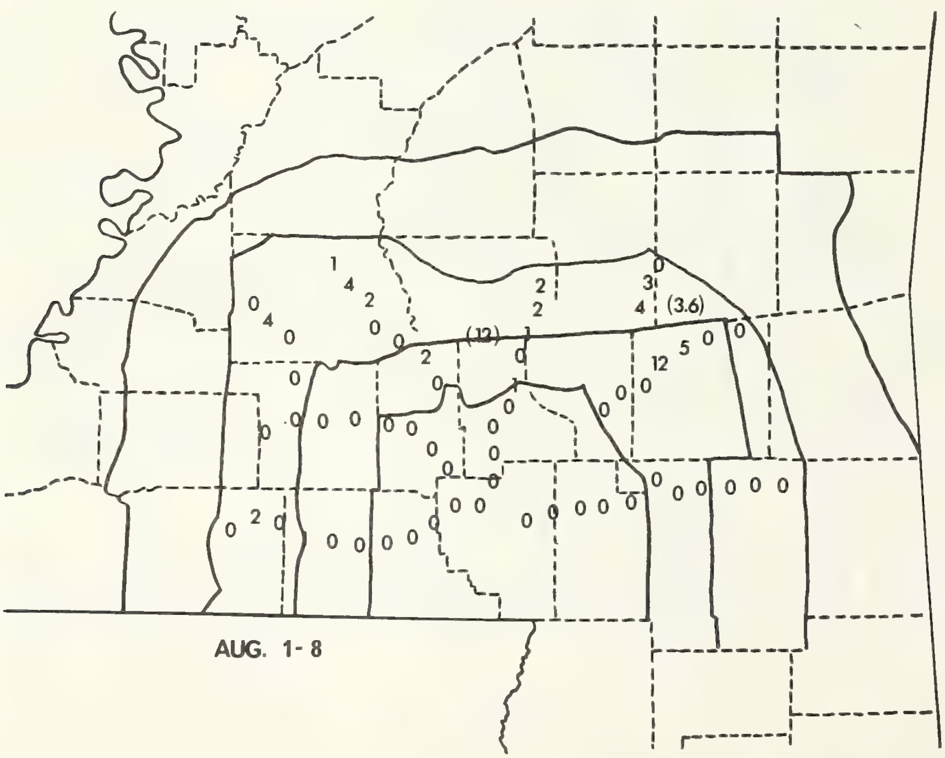

FIGURE 5.—Numbers of boll weevils/5 Leggett traps, Aug. 1–8, 1973. Units in brackets.

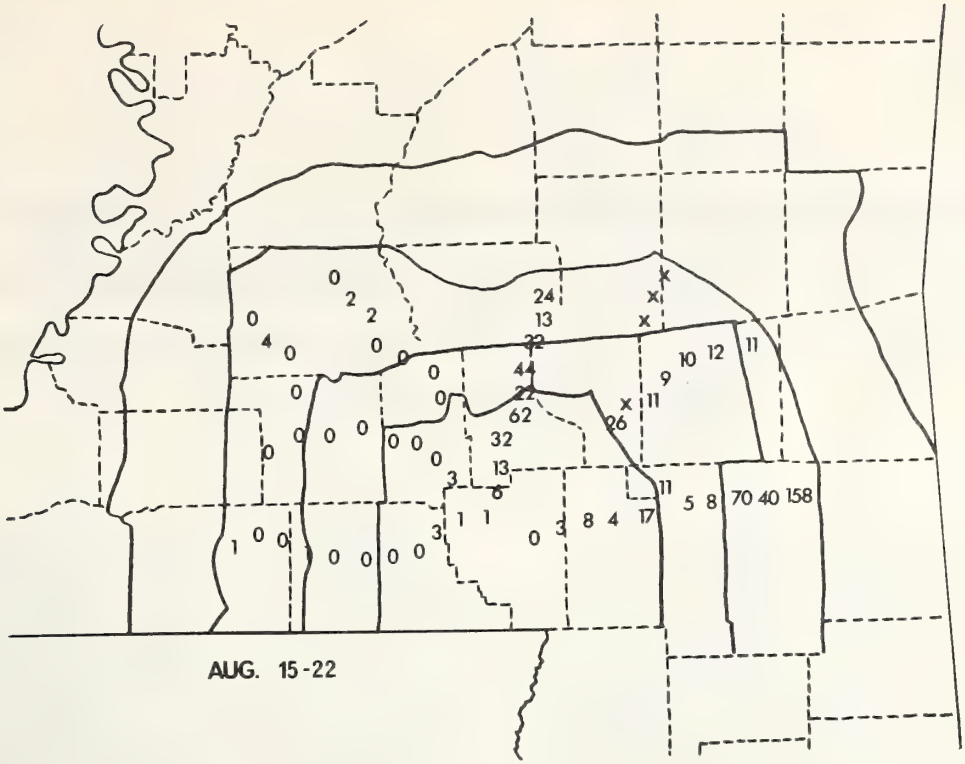

FIGURE 6.—Numbers of boll weevils/5 Leggett traps, Aug. 15–22, 1973.

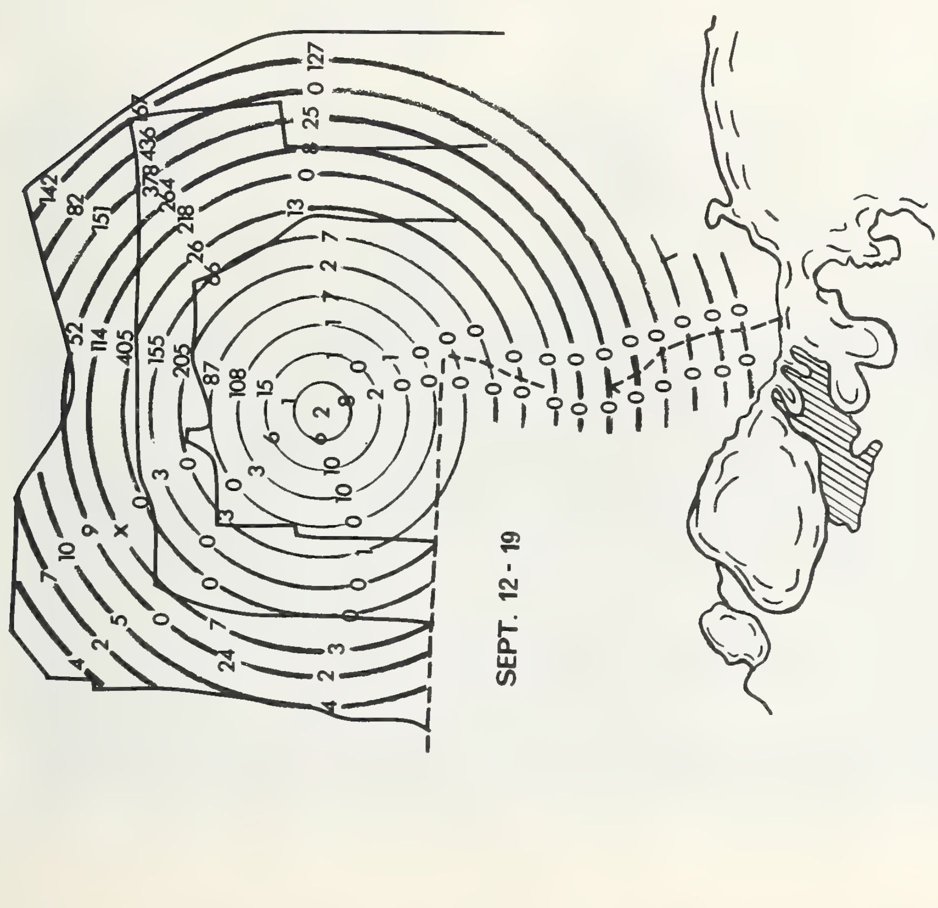

FIGURE 7.—Numbers of boll weevils/5 Leggett traps, Sept. 12–19, 1973.

INTENSIVE SAMPLING OF TWENTY-FIVE SELECTED FIELDS IN ERADICATION AND FIRST BUFFER AREAS OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT IN 1973

By E. P. Lloyd and W. P. Scott[1]

Twenty-five fields were selected in the eradication (zone I) and first buffer (zone II) areas of the Pilot Boll Weevil Eradication Experiment (PBWEE) for intensive sampling to detect the presence of low-density boll weevil populations in these fields from early June until the experiment was terminated August 10. The secondary objective of this study was to determine the relative abundance of boll weevils in the trap crops and normal plantings as the season progressed. Locations of the 25 fields selected for intensive sampling are shown in figure 1.

Criteria for evaluation—The intensive sampling was accomplished with six tractor-mounted insect-collecting machines of the type shown in figure 2. These insect-collecting machines not only collect adult boll weevils from the plants, but from infested flared squares as well.

Estimates of the size of the adult populations in the normal plantings can be made by dividing the number of adult boll weevils collected per acre by the average machine efficiency (65%). As the season progresses, however, machine efficiency in collection of adult boll weevils decreases, since most of the weevils are inside the bracts of the squares. Since the machines also collect infested flared squares, estimates of the size of the infesting population of adult boll weevils can be made from the number of infested flared squares by the following computations:

$$\text{No. of adult boll weevils/acre} = \frac{\text{No. infested squares/acre}}{\text{No. eggs laid/female/day}} \div \frac{\text{machine}}{\text{efficiency}} \times 2.$$

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In this equation the number of eggs laid per day per female is used as the divisor since flared squares usually remain on the plant 1 day after the abscission layer is formed prior to shed. Machine efficiency in collecting flared squares is approximately 80% under average field conditions. The equation is multiplied by 2 to account for male as well as female boll weevils, assuming a 50:50 sex ratio.

If one infested flared square was collected per acre, the following computations would be made to estimate the size of the adult boll weevil population:

$$\text{No. of adults/acre} = 1/7 \div .8 \times 2 = .34 \text{ adult weevils/acre.}$$

Therefore, if only one infested square were collected in an acre sample, the adult population would be estimated to number one per 3 acres of cotton. If one square were collected on 18 acres of cotton, the confidence level would increase to one adult weevil per 54 acres of cotton.

These calculations represent only the random sampling of 1 acre in each field each week in the eight fields sampled intensively in zone I. Since 1-acre samples were taken once each week in each of the fields, an average of three samples per generation was taken for the overwintered generation, as well as for the first and seasonal field generations. Assuming an average 10-fold rate of increase per generation, the probability of collecting first generation weevils was 10 times that of finding an overwintered weevil. Similarly, the probability of recovering a second generation weevil was 100 times as great as recovering an overwintered weevil.

The insect-collecting machines were used to sample the entire trap crop in each of the 25

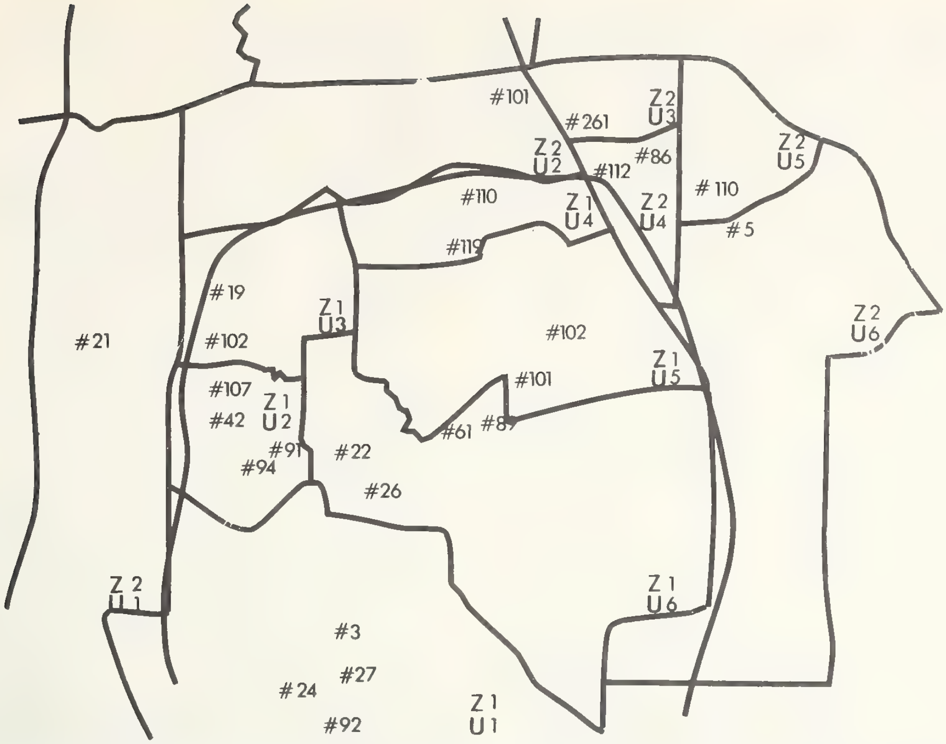

FIGURE 1.—Location of fields sampled intensively in zones I and II in 1973, PBWEE.

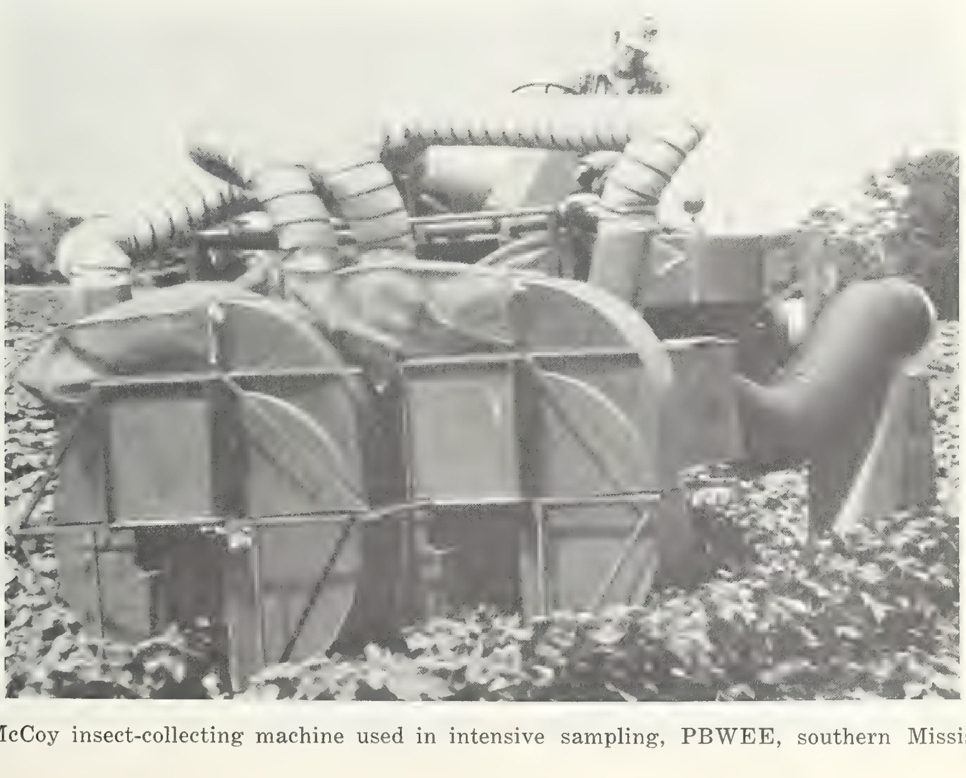

FIGURE 2.—McCoy insect-collecting machine used in intensive sampling, PBWEE, southern Mississippi, 1973.

fields intensively sampled. Machines sampled these trap crops 5 days each week during the 9-week sampling period. Trap crops averaged one-fifth acre in size. Previous studies indicated that most of the overwintered weevils move into the trap crops prior to fruiting in the normal plantings. Because this bias was introduced into the sampling method, precise estimation of the size of boll weevil populations was very difficult. However, this bias increased the probability of detecting boll weevil populations.

In the case of the experiment reported here, detection (presence or absence) is of primary importance. For this reason, emphasis was placed on detection rather than precise estimates of the size of the boll weevil population during the period of evaluation.

Detection of infestations—Boll weevils were detected in every field sampled in the first buffer area except in unit 1, field 21, as shown in table 1. The weevil-free location was in Lincoln County (western part of first buffer area) and was not located in close proximity to the heavily infested fields in zone III, unit 4, as were the other six locations in zone II. Boll weevil populations were suppressed in the first buffer area to a low level with insecticide treatments. These treatments were terminated about August 10.

Adult boll weevils were detected in 6 of the 18 fields in the eradication area (zone I), as table 2 shows. Boll weevil populations in the two northernmost fields in zone I (unit 4, fields 110 and 119) were suppressed with insecticide treatments. Boll weevil infestations detected in the other four fields (unit 3, field 19; unit 5, field 102; unit 6, fields 61 and 89) were eliminated with sterile male weevils, trap crops or both, or with traps. Boll weevils were not detected in the other 12 fields subjected to intensive sampling. All of these were in the southern two-thirds of zone I.

Of the 11 native adult boll weevils collected in the eradication area, 10 were collected from the trap crops. The native adult boll weevil collected in the normal planting was at field 61 in unit 6. This field was planted on April 12, the earliest planting in the area. Because of cold weather in April which caused seedling damage, all but 2 acres of this 30-acre field were replanted in May. The native weevil collected in this normal planting during the last week in June was collected from the 2 acres of the April 12th planting which had survived the adverse weather. In the same collection were 43 sterile male

TABLE 1.—*Intensive machine sampling of trap crops and normal plantings in seven fields in zone II in the PBWEE, 1973*

Date	Trap crop		Normal plantings	
	No. weevils[1]	No. (larvae) infested sqs.	No. weevils[1]	No. infested sqs.
June 4–8	3 S, 1 N[2]	0	...	...
June 11–15	23 S, 7 N[3]	0	1 N[3]	0
June 18–22	15 S, 5 N[4]	[4]3	0	0
June 25–29	8 S, 6 N[5]	[5]12	6 S, 2 N	0
July 2–6	3 S, 2 N[6]	[6]1	2 S, 1 N	0
July 9–13	5 S, 1 N[7]	[7]7	1 S	0
July 16–20	1 S	[8]2	2 S	0
July 23–27	1 N[9]	0	1 S	0
July 30–Aug. 3	1 S	0	2 S, 3 N[10]	0

[1] N = native boll weevil; S = sterile boll weevil.

[2] Collected in unit 4, field 112.

[3] Collected in unit 2, field 101; unit 3, field 119; unit 4, field 112; unit 5, field 110.

[4] Collected in unit 3, field 119; unit 4, field 86, and unit 5, field 110. Larvae collected in unit 5, field 110.

[5] N collected in unit 3, field 119; unit 4, field 86, and unit 5, field 110. Larvae collected in unit 2, field 101; unit 5, field 110, and unit 6, field 5.

[6] N collected in unit 4, fields 86 and 12. Larvae collected in unit 2, field 101.

[7] N collected in unit 5, field 110. Larvae collected in unit 2, field 101, and unit 3, field 119.

[8] Larvae collected in unit 2, field 101.

[9] N collected in unit 2, field 101.

[10] N collected in unit 2, field 101, unit 3, field 119, and unit 4, field 112.

TABLE 2.—*Intensive machine sampling of trap crops and normal plantings in 18 fields in zone I in the PBWEE, 1973*

Date	Trap crop		Normal plantings	
	No. weevils[1]	No. (larvae) infested sqs.	No. weevils[1]	No. infested sqs.
June 4–8	29 S	0	....	...
June 11–15	303 S, 6 N[2]	0	19 S	0
June 18–22	312 S, 1 N[3]	0	43 S	0
June 25–29	222 S, 2 N[4]	[4]1	54 S, 1 N[4]	0
July 2–6	84 S	0	10 S	0
July 9–13	21 S, 1 N[5]	0	9 S	0
July 16–20	6 S	[6]1	12 S	0
July 23–27	4 S	0	2 S	0
July 30–Aug 3	4 S	0	0	0

[1] N = native boll weevil; S = sterile boll weevil.

[2] Collected in unit 3, field 19; unit 4, fields 110 and 119; unit 5, field 102; unit 6, fields 61 and 89.

[3] Collected in unit 6, field 89.

[4] N collected in unit 4, field 110; and unit 6, fields 61 and 89; larva collected in unit 6, field 61.

[5] Collected in unit 3, field 19.

[6] Collected in unit 4, field 110.

boll weevils. No other native adults or infested squares were detected in the field for the remainder of the season. The field was not treated with insecticides, and we assume that the population was eliminated with sterile-male releases, since a native female weevil was collected in the normal plantings.

One native female boll weevil was collected on July 12 in a trap crop in unit 3, field 19. This native female weevil was confined on cotton squares for egg laying. None of these eggs hatched.

Two infested squares were collected from trap crops. One was collected during the last week in June from unit 6, field 61. The trap crop only was treated with insecticides. No adult native weevils nor infested squares were detected in this field for the remainder of the sampling period.

The other infested square collected during the week of July 16–20 was from unit 4, field 110, the northernmost field sampled in the eradication area. Since there was considerable evidence from other sources that migration of weevils had occurred into the northern one-third of the eradication area, this field was treated twice weekly with sprays of azinphosmethyl.

Intensive sampling with the insect-collecting machines was compared with the other methods used to detect boll weevil infestations in the PBWEE, which included Leggett traps, adult surveys, and larval surveys. The four sampling methods are compared by units in table 3.

In unit 1, in the four intensively sampled fields, no weevils were detected by intensive sampling, by traps, by adult surveys, or larval surveys. Similarly, in unit 2, in the four fields intensively sampled, no weevils were detected by any of the sampling methods.

In unit 3, two fields were sampled intensively, and in one field, two adults were detected in the trap crop by intensive sampling. In the same field, four weevils were collected in traps, but no other adults or larvae were collected in visual surveys. In the second intensively sampled field in this unit, weevils were not detected by any sampling method.

In unit 4, in the two intensively sampled fields, adult weevils were detected in both fields by intensive sampling. (One larva was also collected in one of these fields by intensive sampling.) Weevils were captured in traps at both of these fields. Adult weevils were not detected by field surveys, but larvae were detected in one of the fields during weekly surveys. Both of these fields received insecticide treatments to suppress the boll weevil population.

In unit 5, in the two intensively sampled fields, one adult weevil was collected in one of the fields by intensive sampling. A total of three weevils

TABLE 3.—*Boll weevils detected in 18 intensively sampled fields in eradication area, June 4–Aug. 3, 1973*

Work unit & field No.	Sampling method			
	Intensive sampling	Leggett traps	Adult surveys	Larval surveys
Unit 1:				
Field 3	0	0	0	0
24	0	0	0	0
27	0	0	0	0
92	0	0	0	0
Unit 2:				
Field 42	0	0	0	0
91	0	0	0	0
92	0	0	0	0
107	0	0	0	0
Unit 3:				
Field 19	2	4	0	0
102	0	0	0	0
Unit 4:				
Field 110	[1]1	11	0	2
119	1	9	0	0
Unit 5:				
Field 101	0	1	0	0
102	1	2	0	0
Unit 6:				
Field 22	0	0	0	0
26	0	0	0	0
61	[1]1	1	0	1
89	2	0	0	0

[1] Larva dissected from collected square also.

were collected in traps at these two fields during the 1973 season. Neither adult weevils nor larvae were detected by field surveys.

In unit 6, in the four fields sampled intensively, weevils were not detected by any detection method in the two southernmost fields in the unit. In field 61, weevils were detected by intensive sampling (two adults, one larva), traps (one weevil), and by larval surveys (one larva). In the other field (89) one adult weevil was collected by intensive sampling in the trap crop. The latter field was the only instance in which weevils were detected by intensive sampling and by no other sampling method. With this exception there is excellent agreement of detection procedures.

EFFECTS OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT ON NONTARGET SPECIES[1]

By F. A. Harris,[2] K. K. Shaunak,[2] C. A. Wilson,[2] G. A. Hurst,[3] and C. L. Simmons[2]

A study of the impact of an eradication program on nontarget species is an important and necessary part of any pilot experiment which may lead to large programs. The Environmental Protection Agency requires an environmental impact statement before it will approve programs such as an attempt to eradicate the boll weevil throughout the Cotton Belt. Furthermore, the side effects from an eradication program must be figured into the assessment of costs and expected benefits of the program. Thus, the side effects of the Pilot Boll Weevil Eradication Experiment (PBWEE) on certain nontarget organisms were monitored. The monitoring activities were concentrated in the following three areas: (1) Impact on cottonfield-inhabiting nontarget insect species, including both insect pest species and natural enemies; (2) impact on honey bees frequenting cottonfields from beehives in the vicinity; and (3) impact on nontarget wildlife species. Each of these areas will be addressed as separate sections of this report.

IMPACT ON NONTARGET INSECTS IN COTTON

The most important nontarget (in respect to the PBWEE) insect pests on cotton in the Midsouth are the bollworm, *Heliothis zea* (Boddie), and the tobacco budworm, *H. virescens* (F.) These two species and their natural enemies were therefore of primary interest in this study. Insecticides applied for boll weevil control reduce populations of arthropod predators and parasites that normally regulate *Heliothis* populations in cotton. Evidence of natural regulation of *Heliothis* larvae in cotton by arthropod predators and parasites has been documented by many researchers (Ewing and Ivy 1943; Lingren et al. 1968; Laster and Brazzel 1968; Ridgway et al. 1968; Lewis and Brazzel 1968). These evidences have suggested that if the boll weevil is removed from its position as a key pest in cotton, and insecticides for boll weevil control are eliminated, the cotton agroecosystem will revert to a natural balance in which bollworm and tobacco budworm populations will fluctuate below economic threshold levels during most of the growing season. On the other hand, few assessments have been made of the pest status of the tarnished plant bug, *Lygus lineolaris,* and cotton fleahopper, *Pseudatomoscelis seriatus,* in the absence of cotton insecticide regimes in the Midsouth.

Methods

The impact of the eradication experiment on *Heliothis* spp., tarnished plant bug, cotton fleahopper, and natural enemies was assessed by taking samples from June to October 1971, 1972, and 1973. The samples were taken in the eradication zone and in an area designated normal, where cotton-insect control was carried out by growers in their usual manner. Samples were taken in 4 to 12 fields (field size 6–10 acres) each week in each of the 2 areas.

Sampling consisted of (1) whole-plant examination of cotton on 50 row-ft/field for *Heliothis* eggs, larvae, and damaged fruit, and (2) vacuum sampling of 100 ft^2/field with a D-Vac for tarnished plant bugs, cotton fleahoppers, and natural enemies.

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The fields involved in these samples received the following treatments in the eradication zone: (1970) Seven applications of ULV malathion (1.25 lb/acre) between September 9 and November 9. (1971) Twelve applications of ULV malathion (1.25 lb/acre) between August 9 and October 15. (1972) In-furrow and sidedress applications of aldicarb to the trap crop, i.e., 2%–3% of each field. Weekly applications of foliar insecticides to the trap crops. One pinhead square stage application of malathion or azinphosmethyl, 1 application of toxaphene-DDT-methyl parathion, 1 application of DDT-azinphosmethyl, and 16 applications of azinphosmethyl (0.25 lb/acre) between July 15 and November 26. (1973) In-furrow and sidedress applications of aldicarb to the trap crops, and some foliar applications to trap crops only.

Sampling was terminated in 1973 in fields that received broadcast applications of insecticide. Thus, data in 1973 represent no-insecticide situations except for that applied to the trap crop in 2%–3% of each field, whereas the 1972 data represent heavy insecticide use.

The 1971 and 1972 records of treatment do not show in-season treatments applied by the farmer.

Treatments applied to fields in the "normal" area consisted of various numbers of applications of several recommended insecticides as follows: (1970–1972) Applications ranged in number from 0 to 9 of toxaphene-DDT-methyl parathion mixture, or carbaryl, or methyl parathion-EPN mixture, or methyl parathion alone. (1973) Applications were predominantly azinphosmethyl and ranged in number from four to six.

Results

The data were summarized as seasonal averages for 1971, 1972, and 1973. The data shown in figures 1–4 are for selected groups of predators and show the impact of the eradication program on these natural enemies.

Coccinellids (fig. 1) in 1971 averaged less than 100/acre in both the normal and the eradication areas. In 1972 the heavy insecticide pressure in the eradication area resulted in a seasonal average coccinellid density of approximately 275/acre, while in the still relatively heavily insecticide-treated "normal" area, the density of coccinellids was more than five times greater.

In 1973, under essentially no insecticide pressure, the coccinellids recovered in the eradica-

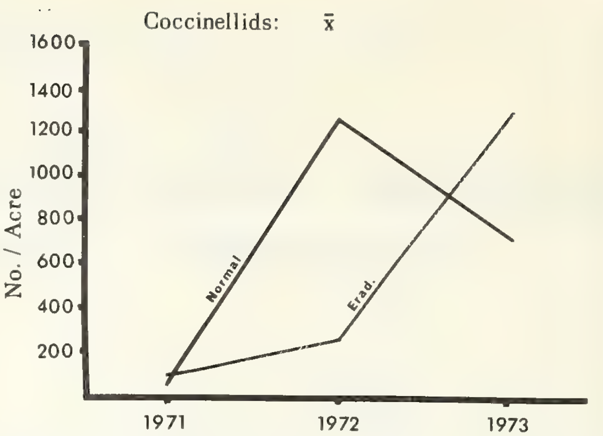

FIGURE 1.—Seasonal average coccinellid densities in cottonfields in the eradication area and in a normal treated area.

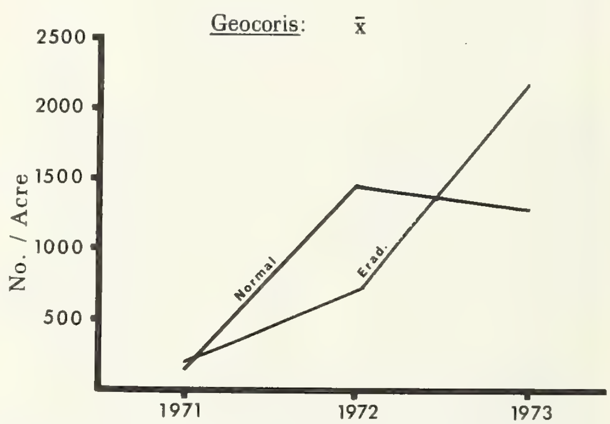

FIGURE 2.—Seasonal average *Geocoris* densities in cottonfields in the eradication area and in a normal treated area.

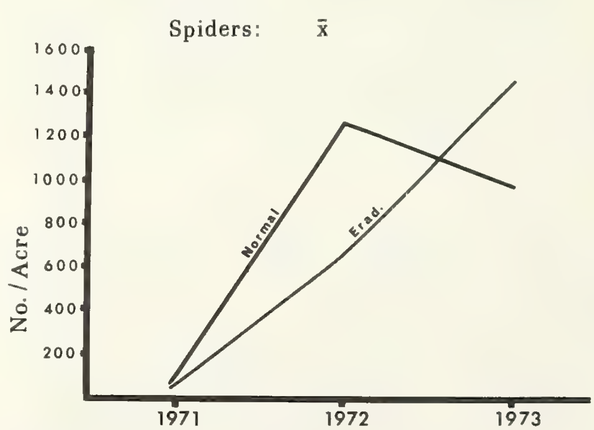

FIGURE 3.—Seasonal average spider densities in cottonfields in the eradication area and in a normal treated area.

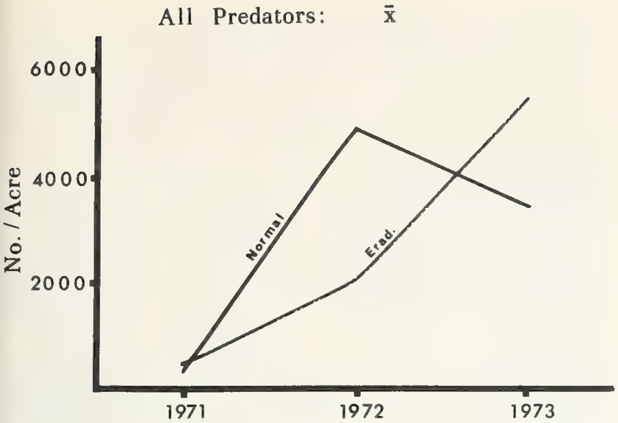

FIGURE 4.—Seasonal average densities of all predators in cottonfields in the eradication area and in a normal treated area.

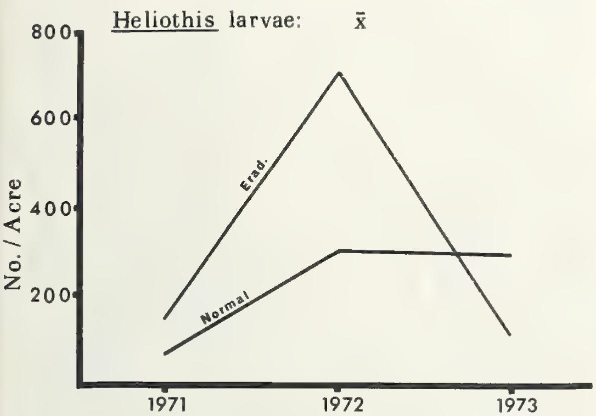

FIGURE 5.—Seasonal average *Heliothis* spp. larval densities in cottonfields in the eradication area and in a normal treated area.

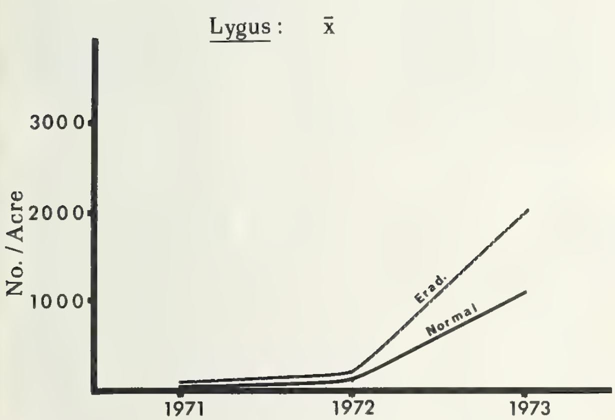

FIGURE 6.—Seasonal average densities of *Lygus lineolaris* in cottonfields in the eradication area and in a normal treated area.

tion area and the situation reversed itself. Populations were higher in the no-insecticide eradication area (about 1,400/acre) than in normal area where in-season insecticides were used (about 750/acre).

Geocoris (fig. 2) and spiders (fig. 3) and other predator groups showed similar patterns during the 3-year period. A summary of effects on all predators is shown in figure 4. The 1971 predator density was approximately 300/acre in both areas. In 1972, under heavy insecticide pressure, the predator population in the eradication area was approximately 2,000/acre, or approximately 40% as high as the population density of approximately 5,000/acre in the "normal" area. These data also indicated a reversal of the situation in 1973, when under no insecticides the predators recovered and their populations were approximately 36% higher than in the "normal" area.

The summary data of the *Heliothis* populations (fig. 5) show an inverse relationship to the predator populations. In 1972, under heavy insecticide pressure, the *Heliothis* population was much higher in the eradication area than in the "normal" area, while in 1973, under no insecticide pressure, *Heliothis* populations were lower in the eradication area than in the insecticide-treated "normal" area.

These data support our hypothesis that under no in-season insecticide regimes, the natural enemies of *Heliothis* spp. will regulate population fluctuations within levels considerably below that now observed in most insecticide programs.

Tarnished plant bug (fig. 6) and cotton fleahopper infestations never reached very high population density levels in any of the fields surveyed. However, these seasonal average data do show that in 1973, under no insecticide treatments in the eradication area, the tarnished plant bugs reached densities almost double that seen in the insecticide treated fields of the "normal" area. Data from tests on untreated cotton in the Mississippi Delta in 1973 show that seasonal average densities of fleahoppers and tarnished plant bugs together exceeded 12,000 bugs/acre. This indicates that these mirids may become increasingly significant cotton pests in the Midsouth, if and when the need for boll weevil insecticides is alleviated.

Increased *Heliothis* populations were observed in fields receiving malathion or azinphosmethyl reproduction-diapause control treatments in the fall of 1970, 1971, and 1972 in the PBWEE. This phenomenon was reported by Bottrell (1969) from observations in the High Plains reproduction-diapause boll weevil control programs in 1967 and 1968. He observed the increased *Heliothis* populations in fall-treated fields, but could measure no effect on size of *Heliothis* populations the following spring. In the south Mississippi experiment some pertinent observations were made relative to these increased *Heliothis* infestations in reproduction-diapause control areas. First, collections of larvae and pupae indicated a high incidence of disease in these populations which caused approximately 40% mortality in larvae and approximately 30% in pupae. The disease-causing organisms were predominantly the fungus *Spicaria rileyii* and the protozoan *Nosema heliothidis.* Second, soil samples in cotton, corn, and soybean fields suggested higher diapausing pupal populations of both *H. virescens* and *H. zea* in the reproduction-diapause control area than in an untreated area. The tobacco budworms in the corn were observed to have developed on a wild host, small flower morningglory, *Jacquemontia tamnifolia* (L.) Griseb., which was abundant in the fields. The soil-sampling procedure was inadequate to obtain good pupal population estimates. However, the indication of possible increased *Heliothis* populations with fall-applied insecticides in cotton is sufficient to warrant further attention to the problem. A small, subtle increase in *Heliothis* populations each year for several years could create a significantly increased cotton pest problem.

IMPACT ON HONEY BEES

Effects of the PBWEE on honey bees, *Apis mellifera,* were monitored during 1972. This study was important for several reasons: (1) The honey bee is especially susceptible to currently used cotton pesticides, (2) the honey bee visits cotton extensively for nectar when cotton is in the bloom stage, and (3) extensive commercial beekeeping is carried out in many areas of the Cotton Belt.

Methods

The experiment was designed to compare the effects of the treatments in the boll weevil eradication area with the "normal" recommended in-season control program of growers outside the eradication experiment area.

Beehives used in the experiment were the standard Langstroth type, and Italian strain bees were used throughout the experiment. All supplies and bees were acquired from commercial suppliers.

The data were obtained from studies of four fields in the eradication area and two fields in a "normal" area. Hives were placed at five distances from each field in both a northernly and a southernly direction. The closest hives were adjacent to the field; more distant hives were at 300, 600, 1,200 and 2,100 feet from the field in each direction. Data reported here are (1) observed worker mortality, (2) brood production, and (3) hive weight.

Observed worker mortality was rated on a 4-point scale, where 1 was very light, 2 was light, 3 was moderate, and 4 was heavy.

Brood production was measured as the number of frames and fractions of frames containing brood in each hive.

Hive weight was measured with a scale and was a true measure of total hive weight, both structure and contents.

Insecticides in the 4 eradication-area fields consisted of 16 applications of azinphosmethyl (0.25 lb/acre) by aircraft, and varying numbers (0 to 12) of peripheral spray treatments by ground sprayer. The treatment period extended from early July through mid-October.

Insecticides applied to the "normal" fields were 8 in one field, applied from late July through mid-September, and 14 in the other field, applied from late July through late October. Insecticides used on these fields varied, and consisted of methyl parathion alone, toxaphene-methyl parathion mixture, toxaphene-DDT-methyl parathion mixture, and in one case a monocrotophos treatment.

Results

Data of bee kills during 1972 show a much higher average kill rating of about 1.5 for the "normal" area compared to the average 0.7 rating for the eradication area. These data reflect the greater mortality caused by the organochlorine insecticides used in the "normal" control area. Caution should be used in interpreting these data since rapid bee kill by organophosphorus insecticides may make them slightly misrepresentative. Rapid kill may have prevented some bees from returning to the hives located at the varying distances away from the field, and consequently their mortality would not be reflected in the ratings.

A summary of bee-kill ratings by months (table 1) shows similar mortality in the eradication and "normal" areas in July when only organophosphorus insecticides were used in both areas. In August the "normal" area kills increased when the farmers began applications of the organochlorine-organophosphorus insecticide mixtures.

The data indicate decreasing rates of kill at increasing distances away from the treated cottonfield (table 2). However, the hives at the greatest distance of 2,100 feet from the field were within foraging range of worker bees, which could have easily visited the treated fields, contacted the poison, and died before returning to the hive.

Brood production data for hives at various distances from the treated fields showed no differences in brood production attributable to distance (table 3).

The data on monthly hive weights (table 4) indicate that hive weights were heavier in the "normal" areas. If the worker mortality observation is a valid measure of actual bee kill by the various treatments, these data indicate a rapid buildup in honey stores in July, followed by heavy worker kill, with the consequence that honey use in the hives went down, leaving a large accumulation of honey to be weighed month after month.

The results of this study indicate that honey bees are less affected by the organophosphorus insecticides used in the eradication experiment than by the organochlorine-organophosphorus mixture used under "normal" conditions.

IMPACT ON WILDLIFE SPECIES

The project to evaluate the impact of the PBWEE on wildlife consisted of field and laboratory phases.

The field work was compiled by Roach (1973). The field phase included both monitoring and experimental projects. Searches of 44 trap-crop plots (aldicarb) yielded only one dead bird. Cause of death was unknown. A total of 2,554 hours (involving 99.6 acres of trap crops) were spent searching cottonfields after insecticide application for dead or affected vertebrates. Two toads, three birds, and two snakes were found. Cause of death could not be exactly determined, but high levels of DDT and toxaphene were found in several of the dead vertebrates. A study of the vertebrate species using cottonfields was made. Many birds and several mammals regularly used cottonfields. One lizard and several amphibians were also found in cottonfields. Feeding chemo-

TABLE 1.—*Monthly average bee-kill ratings in the eradication area and in a normal area*

Month	Bee-kill rating[1]	
	Eradication area	Normal area
June	0	0
July	1.6	1.7
Aug.	1.1	2.8
Sept.	.4	1.9
Oct.	.4	1.2

[1] 1=very light, 2=light, 3=moderate, 4=heavy.

TABLE 2.—*Seasonal and area average bee-kill ratings at various distances from treated fields*

Distance (ft)	Rating[1]
0	1.4
300	1.0
600	.9
1,200	.9
2,100	.7

[1] 1=very light, 2=light, 3=moderate, 4=heavy.

TABLE 3.—*Seasonal and area average brood production measurements at various distances from treated fields*

Distance (ft)	Brood production[1]
0	5.8
300	6.2
600	6.1
1,200	6.2
2,100	5.9

[1] Number of frames of brood.

TABLE 4.—*Monthly average hive weights in the eradication area and in a normal area*

Month	Hive weights (lb)	
	Eradication area	Normal area
June	73	68
July	80	85
Aug.	81	96
Sept.	72	90
Oct.	74	84

sterilized boll weevils to nestling redwing blackbirds (in nests on edges of cottonfields) had no adverse effects. Food habit studies of bobwhite quail chicks and Fowler's toads in cottonfields showed boll weevils to be of little importance as food items. A cottonfield was shown to be much less suitable than a soybean field as brood habitat because sampling of insect populations revealed far fewer insects (lower density and biomass) in the cottonfield due to poisoning. Bobwhite quail chicks, coturnix quail chicks, and Fowler's toads were exposed in cottonfields to normal field applications of malathion, azinphosmethyl and a defoliant (Def) with no adverse effects.

The laboratory phase dealt mainly with the chemical busulfan (Myleran), which was used to chemosterilize the boll weevil. A majority of the research has been published (Kulkarni et al. 1973). Intensive work showed that the force-feeding of chemosterilized boll weevils to coturnix quail chicks had no significant effect on reproductive performance (egg production, fertility, hatchability, shell thickness, albumen, yolk contents).

Gland weights of Fowler's toads force-fed chemosterilized boll weevils were not affected. Acute oral toxicity LD_{50}, subacute toxicity, and the cumulative toxicity index of busulfan were determined for bobwhite and coturnix quail. A study of the distribution and metabolic fate of ^3H-labeled busulfan in bobwhite quail showed most radioactivity to be in the urine and immunobiological tissues, but not in the testes.

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POSTEXPERIMENT DEVELOPMENTS OF THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By M. E. Merkl[1]

Following completion of the Pilot Boll Weevil Eradication Experiment (PBWEE) on August 10, 1973, no suppression measures were taken in the experimental area, but W. H. Cross and members of his group (Agricultural Research Service) continued their long-range movement studies. A line of traps was installed south from the center of zone I along either side of the Pearl River down to Slidell, La. Five Leggett traps were installed at 5-mi intervals along the line. Traps were baited and checked for weevils weekly. The captured weevils were sexed and examined to determine whether they were native weevils, ebony, or bronze.

E. P. Lloyd and members of his group (Agricultural Research Service) continued examinations of 25 fields which had been intensively sampled during the experiment. Four in-field traps were installed in each field (17 in zone I, 8 in zone II), and Leggett traps were installed around the fields at the rate of one trap per acre of cotton. Insect-collecting machines were also used in these fields until cotton began to open. After cotton was open, 100 ft of row per field was checked for weevils by shagging. All weevils captured were brought back to the Boll Weevil Research Laboratory and checked to determine whether they were native, ebony, or bronze weevils.

D. D. Hardee's group (Agricultural Research Service) checked 19 other fields in zone I, and 12 fields in zone II. In-field traps, Leggett traps, shagging, and square examination on 100 to 300 row ft per field were all used to evaluate the buildup of weevils in the area following the end of the PBWEE. All weevils captured were brought to the laboratory for sexing, and again determinations were made as to whether they were native, ebony, or bronze weevils.

During 1973, Leggett traps were used extensively to survey native overwintered and subsequent generations of the boll weevil throughout the PBWEE area to determine relative population levels and long-range movement in the different zones. Trap sites were located in radiating lines at 5-mi intervals from the center of zone I. From 40 to 99 sites were operated with 5 traps per site after August 1.

Results of the trapping after August 1 were as follows: (August 1–8). Sites in zone I were negative, but the beginning of fall migration was indicated by captures in zone II. (August 15–22). Considerably increased overall captures and a clear gradient of decreasing captures into the center of zone I suggested long range movement from outside, especially from north central areas. (September 12–19). Peak captures occurred during the fall migration period. A gradient was still evident into the center of zone I. Movement south of the center of zone I was shown by the newly located line of traps along the Pearl River. It was concluded that at least most of the adult weevils captured in zone I by noncottonfield-oriented traps in August were migrants from outside the area.

Ebony weevils which had been released in the sterile-male program were also captured by the Leggett traps. During the period of August 1–22, only three ebony weevils were captured in zone I. On August 22, 29 new Leggett trap sites (five/site) were located along each side of the Pearl River at 5-mi intervals to 75 mi south of Morgantown, Miss. Eleven male and four female weevils were captured between August 22 and September 26 at the 12 sites nearest to Angie, La. These weevils are believed to have flown from field 43, 2 mi west of Angie. The most distant capture was a male taken 14.3 mi south of this field. In addition, two ebony weevils were captured in the northern part of zone I, a female in zone II, and a male in zone IV. This male was captured on September 10, 34 mi from the nearest release field. A more detailed discussion of Lloyd's results follow.

Two in-field traps were installed in each of 25 fields in zone I on August 22 and 23. The traps were inspected on August 24 in five fields, and on August 27 in all the other fields. A total of

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7 ebony, 1 bronze, and 24 native weevils was caught in the traps. A breakdown by units showed 6 ebony weevils captured in units 1 and 6; 1 ebony, 1 bronze, and 12 native weevils in units 2 and 5; and 12 native weevils in unit 3. Zero weevils were captured in unit 4, which had been treated with insecticides prior to the end of the experiment. Traps at 10 of the 25 fields captured weevils. During this same week no weevils were captured in nine fields sampled with the insect-collecting machine in zone I. In zone II, 522 native weevils and 1 ebony weevil were collected by machines in 7 fields. Six of the seven fields were infested.

During the week of August 30, Leggett traps were installed around fields. Nineteen native, 6 ebony, and 1 bronze weevil were captured in 18 fields in zone I on in-field traps. This same week 39 native, 8 ebony, and 0 bronze weevils were captured on Leggett traps. A breakdown by units showed 10 ebony weevils captured in units 1 and 6; 18 native, 3 ebony, and 1 bronze in units 2 and 5; and 40 native and 1 ebony in units 3 and 4. Because of rain the insect-collecting machine was not operated during this week. Eight of 18 fields were infested.

Both types of traps were baited and checked weekly for weevils during the remainder of the year. One hundred feet of row per field was also shagged each week. The insect-collecting machine could not be operated because cotton was open in all fields by this time.

Time will not permit a report on each week's catch of weevils, but I will show the summarized results of catches made at 3-week intervals, or roughly after each succeeding generation. During the week of September 21, a total of 97 native, 2 ebony, and 0 bronze weevils was captured on in-field traps in zone I. Four hundred and fifty-three native weevils, and no ebony or bronze weevils were captured on these traps in zone II. The Leggett traps captured 254 native, 4 ebony, and 0 bronze weevils in zone I and 627 native, 0 ebony, and 0 bronze in zone II. Shagging caught 12 weevils in zone I and 32 in zone II. Results for the weeks of October 12, November 2, November 23, and December 7 are shown in table 1.

D. D. Hardee's crew has been checking fields in zone I and zone II since August 20 following the end of the PBWEE on August 10, 1973. Types of checking include Leggett traps around the field, in-field trapping, square examination (200 to 300 per field), and shagging 100–200 row-ft/field.

Weevils were collected at all fields using the Leggett traps during August and September. The in-field traps collected weevils in all fields except one. In this field vandals destroyed the traps and prevented detection by this method. Infested squares were collected in 24 of 29 fields examined during the period. Adult weevils were collected by shagging in 28 of 29 fields.

Summarized results of 29 fields examined appear in table 2. These records show that weevil populations were reduced in zone I below zone

TABLE 1.—*Collection of boll weevils by indicated survey method, October, November, and December 1973, following PBWEE*

[N=Native, E=Ebony, B=Bronze]

Week and zone	In-field traps			Leggett trap			Shagging			Avg. No. weevils caught/field
	N	E	B	N	E	B	N	E	B	
Oct. 12:										
I	130	8	8	114	7	6	22	0	0	16
II	282	0	0	531	0	0	27	0	0	120
Nov. 2:										
I	148	31	52	148	29	34	15	5	0	26
II	214	0	6	[1]543	0	14	11	0	0	112
Nov. 23:										
I	76	32	31	44	49	30	12	1	0	19
II	45	0	1	135	0	3	24	0	0	39
Dec. 7:										
I	73	28	48	392	59	77	3	0	0	37
II	67	0	0	174	0	2	59	0	0	43

[1] Stalks were destroyed in 1 field; 239 weevils in Leggett traps.

II for more than two generations following the end of the experiment.

After the experiment was officially terminated on August 10, research in zones I and II was initiated as a followup measure to determine how rapidly boll weevils could increase from extremely low levels after all suppression measures were removed. The results showed at least a low-level infestation in all units except I-2 by August 27. During September 10 to September 17 all units showed an increase in populations, some to extremely high levels. The results are summarized in table 3. The range of weevils per acre in zone I on September 17 was from 33 to 3,013. In zone II the range of weevils per acre was from 105 to 1,048.

Two potential problems associated with the sterile-male release were: (1) Release of about 2% females from errors in sexing, and (2) release of insects that were not totally sterile. Field 43 (3 acres, zone I, unit 1), located about 2 mi west of Angie, La., showed the results of the interaction of these two problems.

On August 23, two in-field traps were installed in field 43 and baited with grandlure. On August 24, one ebony male and one ebony female were collected in the traps. On August 28, eight egg-punctured squares were collected from the field. These squares yielded 7 larvae (3 first, 3 second, and 1 third instar) and one good egg. In-field traps on the same date contained one ebony male, one ebony female, one native male and three native females. The same traps contained two ebony males and two ebony females on August 29. During the first 3 weeks in September, 64 ebony, 150 bronze, and 6 native weevils were captured in the 2 traps. On September 19, 25 weevils were collected by shagging 100 ft of row. There were 6 ebony, 17 bronze, and 2 native weevils in this collection. Another shagging collection of 74 weevils had 64 ebony and 10 bronze weevils. From August 24 until January 23, a total of 1,295 weevils were collected from this field. Ten native weevils were captured on January 23. This field is unique since it was the only field in zone I found to develop a general field infestation during August.

On December 10–13, 1973, woods-trash samples were collected from zones I, II, and III, and an outside sample was also collected along the Natchez Trace for comparison. Each sample consisted of 2 yd^2 of suitable woods trash taken from areas adjacent to cottonfields. Varying numbers of samples were taken from each field. These records show an average of 48.4 weevils per acre in woods trash in zone I compared with 1,452 per acre in zone II, 15,488 per acre in zone III, and 7,018 per acre outside the area.

TABLE 2.—*Summary of field infestation data and trap collections for August and September 1973 (zones I & II), PBWEE*

Location and date	No. fields	Percent weevil-punct./acre	No. weevils per— Acre	In-field trap	Leggett trap
Zone I[1]:					
Aug.	18.0	1.5	.....	0.59	0.30
Sept.	18.0	5.1	280.0	4.2	2.6
Zone II:					
Aug.	17.0	1.3	.....	.....	5.8
Sept.	17.0	4.9	345.0	30.1	14.9

[1] A gradient was apparent during August and September in zone I from south to north as expressed by numbers of weevils/trap (0.5, 2.1, and 4.6) and by percent punctured squares (1.4, 2.2, and 8.1).

TABLE 3.—*Summary of trap collection of weevils and field infestations following PBWEE, 1973*

Location	Aug. 22 Weevils/trap	Aug. 22 % punct.	Sept. 3 Weevils/trap	Sept. 3 % punct.	Sept. 10 Weevils/trap	Sept. 10 % punct.	Sept. 10 Weevils/acre	Sept. 17 Weevils/trap	Sept. 17 % punct.	Sept. 17 Weevils/acre
Zone I	.5	2.5	2.2	5.5	1.6	5.9	458	5.6	6.2	832
Zone II	6.8	1.7	5.8	1.5	10.2	8.2	1,768	12.2	3.25	479

REPORT OF TECHNICAL GUIDANCE COMMITTEE FOR THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By E. F. Knipling[1]

The Technical Guidance Committee for the Pilot Boll Weevil Eradication Experiment was appointed by the Office of the Secretary, U.S. Department of Agriculture, in July 1971. The names of the 18-member committee and their affiliations are listed below. The committee members came from the U.S. Department of Agriculture, State agricultural experiment stations, universities, and the cotton industry, and represented organizations concerned with research, control, extension, regulatory, and industry activities. The committee met on 11 occasions to discuss plans, review programs, and to consider budgetary matters. It made recommendations to the program and to agencies sponsoring the experiment.

On August 30, 1972, after the experiment had been completed and after considering the results reported by those engaged in the experiment, the committee issued the following statment:

STATEMENT BY THE TECHNICAL GUIDANCE COMMITTEE FOR THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

The Technical Guidance Committee for the Pilot Boll Weevil Eradication Experiment has maintained close contact with the progress and problems in the conduct of the experiment from the time of its initiation in August 1971 and its termination in August 1973. The purpose of the experiment was to determine if it is technically and operationally feasible to eliminate populations of the boll weevil by integrating several suppression techniques while concurrently making improvements in the application of available technology.

The experiment, centered in southern Mississippi and in adjacent areas in Alabama and Louisiana, is representative of the worst boll weevil conditions likely to be encountered in the boll weevil belt. The suppression methods involved the application of insecticides, the use of the boll weevil aggregating and sex pheromone (grandlure) in traps and trap crop planting, the release of sterile males, and the institution of certain cultural measures, including restricted planting dates, early stalk destruction, and the use of cotton growth inhibitors. Much new information was obtained on the biology, ecology, dynamics, and behavior of the boll weevil that is relevant to the development of suppression strategies. Based on the results and experiences gained in the conduct of the experiment, the Guidance Committee has reached the conclusion stated below and offers recommendations to appropriate agencies for additional research and development that is urgently needed to implement and to achieve maximum effectiveness and economy of operations in the event that a national program is undertaken to eliminate the boll weevil as an economic pest in the United States.

I. Conclusion

Based on the results and experiences gained in the Pilot Boll Weevil Eradication Experiment conducted in south Mississippi and adjacent areas in Alabama and Louisiana, and mindful that the experiment was conducted in an area representative of the most severe boll weevil conditions likely to be encountered in the boll weevil belt, the Technical Guidance Committee has reached the conclusion that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that are ecologically acceptable. The economic and environmental benefits of achieving this goal will far exceed the costs that will be involved. For such program to be successful, it must be carried out with thoroughness and precision. The participation of a number of agencies will be required. Complete cooperation and participation by all cotton growers in the boll weevil belt is essential.

II. Recommendations

In the conduct of the pilot experiment, it became apparent that improvements in technology and/or operational procedures for certain suppression components will be necessary to maximize efficiency and economy in the elimination of the boll weevil. Accordingly, the Committee recommends that while detailed plans and facilities for the initiation of a program are under develop-

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ment, research be continued and intensified immediately to further improve the technology and operations relating to the following:

1. Improve mass-rearing procedures to assure the capability of producing adequate numbers of high-quality boll weevils for sterilization and release.

2. Improve techniques of sterilization to assure the attainment of maximum and consistent high levels of sterilization with a minimum detrimental effect on the vigor and mating competitiveness of the males.

3. Develop new methods of sterilizing both sexes of the boll weevil so as to obviate the cost of separating sexes and to reduce costs and logistic problems associated with the feeding of boll weevils for 6 days before they are released.

4. Continue investigations on grandlure to develop the most effective and least costly method of employing the attractant for: (a) suppression, (b) as a means of detection and population assessment, and (c) as a means of monitoring progress in population suppression.

In recommending the urgency of research on the items listed, the Committee does not wish to minimize the need for continuing investigations on other aspects of the boll weevil problem. It is important that ecological research be continued and intensified in various areas of the boll weevil belt, particularly to obtain information on the time of the season and the proportion of field populations that enter hibernation and to locate optimal hibernating sites. Such information is especially relevant to decisions on the degree of in-season control that should be attained by growers, and when the reproduction-diapause suppression component should be initiated. Also, accurate information on the time and proportion of the boll weevils that emerge from hibernation is needed for various areas in order to establish appropriate planting dates and to determine when to apply the pheromone and sterile male release components for maximum effect.

Additional information in various areas on possible differences in the response of boll weevils to pheromones during the late season migration period, during spring emergence from hibernation, and while boll weevils are in cottonfields is also necessary to develop optimal strategies for suppression and detection of boll weevils by the use of the pheromone, grandlure.

There was considerable discussion on the exact wording of the reference to elimination of the boll weevil. Some members felt that the experiment demonstrated the feasibility of eradicating or eliminating the boll weevil from the United States; other questioned this. The wording ". . . it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States" was proposed by those who did not agree with the stronger statement. The statement as presented was adopted by unanimous vote of the committee.

It seems apparent that individuals make different interpretations of the statement. However, in my view, if a program carried out with thoroughness and precision, and with the complete cooperation of all cotton growers as prescribed, will reduce boll weevil population to the level indicated, it will be readily possible to eliminate populations from isolated areas by the application of new techniques that have maximum effectiveness at extremely low levels. The overall plan for a boll weevil elimination program developed by the National Cotton Council's Special Study Committee for Boll Weevil Eradication provides for continuing surveillance and elimination of incipient populatons from border areas to the South.

I would like to add some of my own views on the justification for undertaking an effort to eradicate the boll weevil from isolated regions apart from the report on the activities of the Guidance Committee. There is no question of the importance of the decision that is eventually made on this issue by the scientists and administrators, or of the responsibility they will bear to make the best decision possible. There seems to be general agreement that there is an urgent need for a better solution to the boll weevil problem. From this point of agreement there are widely divergent views as to what would be the best course to follow. All new scientific advances or proposed new approaches to problems have elements of uncertainty and controversy until they have been put to the test for which they are designed. Views as to whether we do or do not have the basic technology to justify a boll weevil eradication effort range from almost full confidence of success to almost certain belief that such effort would fail. Given such divergence in viewpoints, I would like to comment on the consequences of a decision to undertake an eradication program even if it failed to achieve the objective, versus a decision not to undertake a program that unknowingly would have been successful.

Based on the overall plan for a boll weevil elimination program developed by the National Cotton Council, the estimated cost of an eradication program is of the order of $650 million. This cost estimate is cited as one of the principal reasons for not undertaking an eradication program. Perhaps no more than $100 million to $150 million would be involved during an initial period of 2 to 3 years. By this time our ability or lack of ability to achieve eradication in an actual operational program should be known with reasonable certainty. If such investment is made, it seems important to consider whether there would be any significant benefits from the program even if the primary objective were not achieved because of technical and operational problems. I think there would be very important benefits in spite of the failure to eliminate the boll weevil population from the area included in the program.

First, much of the investment will be returned in benefits to affected growers in terms of increased yield and reduced cost of boll weevil control for the 2 or 3 years during which such effort is made. Second, it would provide jobs for a large number of personnel. Third, the technical information and experience gained in even such an unsuccessful effort could provide new information and operational experience that cannot be obtained in any other way. Fourth, the information and experience gained, especially in developing and applying new techniques, may be necessary to devise an effective boll weevil management system without in-season applications of insecticides, or even without the use of any broad-spectrum insecticides.

Thus, the real cost in relation to benefits should be much below the actual investment in an eradication effort and could lead to economic and environmental benefits far exceeding costs even if the initial objective were not realized. If the initial effort proved successful there would of course be ample justification for continuing the program to its ultimate conclusion.

It seems important to also consider the consequences of the opposite interpretation of the status of our technology for boll weevil elimination. If the results of the pilot experiment and other investigations are erroneously interpreted as negative, and if such misinterpretation leads to a decision by the cotton industry, agricultural administrators, and Congress not to undertake an eradication program that could be successful, what would this mean in terms of losses and effects on our environment?

First, the economic losses to farmers, to the cotton industry as a whole, and to our Nation's economy could accrue to tens of billions of dollars in the next 30 years. Second, it could jeopardize the continuation of a profitable cotton industry on millions of acres with dire economic and social effects if the boll weevil or the bollworm and budworm should become resistant to insecticides. Third, it could lead to an increasingly critical problem of bollworm and budworm control by nonchemical means, causing losses not only on cotton but on other crops to the extent of additional billons in losses over a period of years. Fourth, it could result in a continuation of insecticide use in the production of cotton and other crops indirectly affected that presently amount to more than one-third of all insecticides used in our agricultural environment each year. The long-range environmental impact of such otherwise unnecessary environmental pollution could be as important as the economic losses cited.

There is no question that we are considering a program that would be costly. The magnitude of the program under consideration and the great difficulties that would be involved in its execution far exceed any similar program in the past. I am sure that those responsible for making the final decision in this matter will carefully consider all aspects of the problem before making their decision. However, I believe that the above is a valid assessment of the economic and environmental considerations and that it should be taken into account in arriving at any final determination concerning boll weevil eradication.

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REPORT OF ENTOMOLOGICAL SOCIETY OF AMERICA REVIEW COMMITTEE ON THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

By W. G. Eden[1]

The Committee met three times during the 1973 growing season in Mississippi with the Technical Guidance Committee. These meetings allowed us to understand the technical and logistical components of the Pilot Boll Weevil Eradicaton Experiment. After many hours of discussions, we arrived at the following principal conclusions:

1. We were deeply impressed with the vast amount of information about the boll weevil that was brought to bear upon the eradication attempt and the organization and execution of the logistical aspects of the experiment.

2. We interpret eradication to mean the reduction of a population to zero.

3. We could not agree whether a distinction should be made between "accomplishing eradication" and "demonstrating feasibility of eradication."

4. Eradication was not accomplished in the core area.

5. It was demonstrated that populations of weevils can be reduced to extremely low levels by a regional suppressive program.

6. We could not agree on whether technical feasibility of eradication of boll weevil populations was demonstrated.

7. The Committee had reservations concerning any massive undertaking of eradication without further research to refine suppressive techniques. The following factors need to be further researched prior to planning and implementing future population suppression programs: (a) Improvements in mass production procedures, (b) improved sterilization procedures, (c) improved surveillance techniques, and (d) relative value of suppressive components.

8. The core area was smaller than desirable, and the experiment was terminated short of the optimal time period.

9. Proper and complete suppression methods could not be applied throughout the first buffer zone.

10. We believe that the major difficulties that will attend any massive effort against the boll weevil are likely to be less those of a technical nature than of the operational aspects—particularly "people problems" involved in implementing and carrying out the strategies and tactics chosen for suppression of boll weevil populations.

11. Any large-scale pest suppression or eradication undertaking inevitably brings about an interplay of very diverse social, political, and economic interests; thus, reactions to a proposed boll weevil eradication effort will not be limited to the cotton producing areas.

12. We do not presume to know whether a boll weevil eradicaton effort should be undertaken throughout the Cotton Belt. We do have reservations until such time as currently available suppressive techniques are improved and collectively tested in different geographical and ecological areas.

13. We are convinced that the information and experience gained from this experiment have provided invaluable techniques to growers throughout the Cotton Belt for managing boll weevil populations.

14. We believe the decision regarding attempted eradication of the boll weevil should and will be a socio-political decision. We recommend that a detailed summary of the program be published and that all concerned members of our society—and particularly entomologists—inform themselves as to the long-range environmental and economic benefits that would result from a successful eradication program and weigh those against the costs involved.

[1] Chairman, Department of Entomology and Nematology, University of Florida, Gainesville, Fla. 32601.

THE WILL TO WIN

By Charles G. Scruggs[1]

Nine out of ten creatures on earth are insects. Every millisecond of every minute, every hour, every day, every year, every century, uncountable billions upon uncounted billions of insects are chewing, biting, sucking, boring, destroying, contaminating, debilitating, sickening, and irritating man and his plants and animals. Man has only a very small margin of dominance over insects. Except for God's gift of higher intelligence, man might be overwhelmed by insects. Even so, insects still exact a fearful and horrible toll from the universe and man. No one man or computer has yet been able to calculate how many humans could live on this earth if there were no loss of food and fiber supplies to insects. At the moment—worldwide—it seems safe to say that insects and the diseases they spread and spawn consume or destroy more food and fiber than is consumed by man.

Partly because of efficiency of insect control methods in the United States, the American people are the first civilization to live in and enjoy a food abundance. Yet, in spite of all our efforts, the United States is only a bare step away from severe food shortages. With food and fiber supplies the world over at low levels, a single insect plague in the United States could produce world panic. For example, with world wheat supplies at their lowest level in modern times, a severe insect plague in the U.S. winter wheat belt could exact a severe toll. It's been estimated that a swarm of locusts—as have visited the United States in the past—could destroy in a single day enough wheat to supply 5 million people.

One of the most nauseous, deadly, and costly pests in terms of food destruction potential in the world is the screwworm, or, as it's called in Mexico, "gusano barrenador de ganado" (boring worm of livestock). This terrible flesh-eating worm, which attacks and infests man and animals, has the potential to decimate the livestock populations of the Southern United States. This rapacious pest has probably killed and maimed more humans in Central America, South America, and lower North America than all the wars in these areas.

The screwworm—so called because of its resemblance to a wood screw—was considered a plague of the season in early Mexican and United States history. It exacted its horrible toll of calves, lambs, fawns, kid goats, colts, and adult livestock and wildlife every year. It came as a part of the spring season and wreaked its death and damage as unvaryingly as the season—a sort of miasma that plagued man and his animals through the centuries. That is, it killed and maimed until man peered into the very intimacies of its life cycle and devised what has been described as the "single most original entomological thought in the 20th century."

You perhaps know the story. USDA scientists, principally E. F. Knipling and R. C. Bushland, devised the male sterility theory. They and their associates found a way to break the life chain and population dynamics of the screwworm through the introduction of male screwworm flies whose basic gene structure had been so aberrated or changed through exposure to atomic irradiation that the eggs resulting from their matings were sterile. Or put another way, screwworms were induced to breed themselves out of existence.

Starting in the late 1950's in Florida, a massive program to rid the United States of the screwworm was kicked off. The pest was causing an estimated annual loss of $200+ million across the lower half of the United States. The technique was simple—reduce screwworm populations to low levels through weather or other

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means; produce great numbers of male screwworm flies in the laboratory factory; irradiate them; then release in sufficient numbers to overwhelm the native population. Result: After only 3 years of effort, the screwworm was eradicated from the Southeast. Since 1959, there has not been a single case of screwworms in the Southeast unless it was introduced from elsewhere!

Livestock producers in the Southwest, where the screwworm was also a costly pest, heard of the amazing program in Florida and the Southeast. They wanted to do the same thing. But, there were gigantic differences: the area was 100 times the size of Florida, and the Southwest annually was reinfested from Mexico. An eradication program in the Southwest was considered beyond the resources and technology available. Thus, no program for the Southwest.

But livestock producers in Texas, New Mexico, Arizona, Oklahoma, California, and Louisiana were not to be denied. They organized the Southwest Animal Health Research Foundation and then voluntarily invested $5 million in the foundation. They said to State legislatures and the USDA: We want to get rid of the screwworm!

I had the pleasure to serve as one of the organizers and president of the foundation. I've written a book called "The Peaceful Atom and Deadly Fly" that is to be published soon that tells of this program in detail.

But, to make a long story short: through the partnership of producers, State governments, and Federal Government, screwworms were eliminated from the United States in 1966. Since that time we've been engaged in a program to prevent the screwworm from reentering. A joint United States-Mexico program was established a year ago. By 1976 we expect the United States and Mexico to be free of the screwworm. The program represents man's most unique triumph over insects over a major geographic area of the world! Dollar savings—$1 billion over the last 10 years!

That is, it was man's greatest insect control effort until now. Now you and your associates are deciding that you will no longer live with the boll weevil! Using the same basic techniques—reducing populations to low levels, introducing sterile insects to search out and break the reproductive cycle, and exercising eternal vigilance—you plan to get rid of the boll weevil.

I won't recount the detailed plans you have devised. You know them. But, let me give you some suggestions learned from 13 years of similar effort.

1. You must decide you will persevere in the effort in spite of all costs, all the doubters, grumblers, second guessers, and negative thinkers that will rise up to bedevil you!

2. You should title this effort a Cotton Environmental Protection Plan.

3. You must insist—and then make sure all carry out their proper roles—that this is a joint effort between producers, the States, and the Federal Government! Anything less than a full partnership by all concerned will doom this effort to failure and perhaps thereby abort all other similar efforts in the future.

4. You must be prepared to work hard for long years.

5. You—every single one of you—must stand up and be counted time after time! And you must recruit and ally thousands of others who must do the same.

6. Remember that this effort will require more guts, work, intelligence, and dedication than any other single thing any of you have ever before attempted. You must in effect pledge your honor, your work, your devotion to this effort once you start.

You will succeed! Why do I know this? I have a good authority on which to base the statement. Genesis, Chapter 1, Verse 28, says this: "And God blessed them, and God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth."

This is the basis for our will to win! This is the correct view—not the statements of Rachel Carson who wrote: "The 'control of nature' is a phrase conceived in arrogance, born in the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man."

Nature *does* exist for the convenience of man, for the Bible tells us so. That's why you will win!

APPENDIX

From January 20, 1903, issue of The Progressive Farmer

EARLY COTTON AND THE COTTON BOLL WEEVIL

The Mexican cotton boll weevil is becoming a very serious pest in Texas, and about two weeks ago 500 Lone Star farmers met in Dallas to consider ways and means of checking its ravages. They effected a regular organization—the Texas Boll Weevil Convention—appointed a permanent executive committee, and will ask the Federal Government, as well as their State Legislature, to aid them in their work. The following statement is made, we believe, on the authority of Prof. W. D. Hunter, of the United States Department of Agriculture:

"This pest eats cotton only, no other food. Being a tropical insect, it was supposed that it would not go above the limit of volunteer cotton, say Waco, but it has already neared Dallas, and has been found in isolated places further north. The entire Cotton Belt is now threatened. It has appeared in Brazil and Cuba, and has been reported from the West Coast of Africa. It has come to stay; it cannot be exterminated, but it can be kept in check."

One of the methods of checking it is by planting early varieties, and the following letter from Secretary J. H. Connell, Dallas, Texas, to Dr. B. W. Kilgore, of the North Carolina Experiment Stations, should have the attention of Progressive Farmer readers having such seed for sale:

"From inclosed printed matter you will note the nature of the contest we are now waging against the boll weevil in Texas. I wish to call on you for assistance to the extent that you furnish me promptly with the addresses of all originators of early maturing varieties of cotton whose addresses are known to you. We wish to secure large quantities of early maturing varieties from every reliable source to be shipped to this executive committee in carload lots from points beyond the boll-weevil infested region. There may be some North Carolina farmers known to you who cultivate early maturing varieties exclusively, who have seed on hand for sale."

Dr. Kilgore asks that interested parties correspond directly with Professor Connell at Dallas. The seriousness of the movement may be guessed when we say that the recent Convention claimed that the pest cost Texas growers fully $20 million last year.

BIOMATHEMATICAL BASIS FOR SUPPRESSION AND ELIMINATION OF BOLL WEEVIL POPULATIONS

By E. F. Knipling[1]

The use of models as aids to a better understanding of insect population dynamics and insect population suppression methods has emerged as one of the most important aspects of research in the field of entomology. Models to predict the seasonal or periodic changes in populations of many of the important pests of agriculture and forestry are under development at a number of institutions. Some of those investigations involve intensive data collection and analyses by data processing facilities. Information from such studies, properly interpreted and used, should be helpful in planning better and more effective tactics and strategies for the management of some of our major insect pests in the future. It is generally recognized, however, that there are limitations to the degree of confidence that can be placed in results of simulation strategies for coping with insect problems. In the final analysis it is still necessary to put proposed strategies to test under field conditions. Nevertheless, simulation suppression models will become of increasing value as guides to research and to insect suppression programs.

While extensive biological and ecological data on insects and a critical analysis of such data by the use of computer hardware can add refinements to insect models, much can be done by assigning estimated values to basic parameters and then making simple calculations to determine the results to be expected from various suppression techniques.

Over the years I have established and tested literally thousands of simulated suppression models for many insects, including the boll weevil, screwworm, pink bollworm, *Heliothis* spp., tsetse flies, tropical fruit flies, gypsy moth, codling moth, and many others. Almost every conceivable method of control, and especially combinations of various methods of control, have been tested in such simulated suppression models. A number of important conclusions on the basic principles and mechanisms of insect population suppression and detection have been reached from such studies. Most of the principles of suppression identified by the use of such models have been confirmed in actual field experiments, and some of the results have been highly predictive of results in actual use of proposed suppression systems. There is reason to have increasing confidence in the usefulness of modeling for establishing principles, and to serve as guides to research and action programs that are likely to lead to more effective or more acceptable means of insect control.

The purpose of this paper is to use population models to show what we can and cannot expect from various systems of boll weevil population management or eradication. The suppression models will involve insecticides, sterile insects, and the boll weevil sex pheromone employed alone, employed simultaneously, or in sequence. I also wish to discuss the potential value of in-field grandlure-baited traps as a means of boll weevil detection and population assessment.

DEVELOPMENT OF A REPRESENTATIVE UNCONTROLLED BOLL WEEVIL POPULATION

It is necessary to establish a representative population model for an insect before calculations can be made to estimate the impact of various methods of control. While it is recognized that the boll-weevil, like all insect pests, is extremely variable in its development, and that

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many factors influence the rate of growth and the size of populations that will develop in different cotton ecosystems, it is nevertheless possible to establish what can be regarded as a representative growth rate for populations developing under favorable boll weevil conditions. In actual control we are generally not concerned with marginal boll weevil conditions. Our major concern is with conditions that are favorable for boll weevil development and which lead to serious losses if control measures are not taken. Thus, the models established will be representative of areas where the pest is a major problem.

The model in table 1 is designed to depict a typical overwintered boll weevil population and the way it will grow if no control measures are employed. Uncontrolled, the population will cause complete destruction of the crop before the end of the season. As noted, the overwintered population is assumed to average 200 reproducing boll weevils per acre (both sexes) during the first generation. In some boll weevil areas, starting populations are often higher. Each generation spans a period of 20 days, except those late in the season. It is assumed that the females deposit an average of six eggs per day during an average egg-laying life of 17 days. Thus, females in a population will average 100 eggs. If 16.7% of the eggs produce adults that average 17 days of reproductive life, it will mean a tenfold increase from one generation to the next unless the maximum density is reached. The tenfold increase rate may of course not hold at high densities. The amount of available squares and bolls in which larval development must take place becomes a limiting factor for high populations or for cotton in which fruiting has largely ceased. Although the boll weevil is not adequately controlled by natural enemies, they no doubt destroy many weevils, and the proportion destroyed probably increases with the boll weevil density. The cotton fruiting depicted represents high-yielding cotton that probably would produce about two bales per acre under favorable conditions.

It is recognized that the number of eggs deposited per day, the length of life, the rate of survival, the number of squares and bolls on the plants, and other variables can deviate from the values assigned. However, the use of representative averages greatly simplifies calculations in models without altering the basic conclusions one can draw from such models.

The infestation levels as shown in the model would probably mean at least 30% reduction in crop yield, but losses are likely to be much higher. The high population in the third generation would no doubt destroy many of the bolls developing from squares that escaped destruction in boll weevil generation 2. This would not only cause substantial reduction in yield, but the infested bolls would result in a higher population than squares alone could produce. In all probability the actual damage would be of the order of 50%. This estimated amount of damage is in line with average losses observed to have been caused by the boll weevil in untreated cotton during the past 30 years or more (Parencia and Cowan 1972). Thus, there is reason to regard the model as a valid basis for estimating the size of populations and the amount of damage the pest is likely to cause when no control measures are applied. The basic model should also be suitable for appraising the population growth and damage when different systems of control are employed.

It is noted that the fourth and fifth generations would develop in late-setting fruit that may not influence the yield, but which could produce many overwintered boll weevils. The maximum size of the population when control measures are

TABLE 1.—*A basic boll weevil population growth model and infestation rates when the population starts with 200 boll weevils/acre and no control measures are applied*

Generation	No. reproducing boll weevils	No. squares and bolls	Egg punctures: Percent	Egg punctures: No.	Percent diapausing boll weevils	No. weevil progeny[1]: Reproducing	No. weevil progeny[1]: Diapausing
1	200	200,000	6	12,000	0	2,000	.....
2 (F_1)	2,000	400,000	30	120,000	0	20,000	.....
3 (F_2)	20,000	200,000	100	200,000	25	25,050	8,350
4, 5	25,050	50,000	100	50,000	75	2,188	6,262
Total	......	......	...	......	..	.....	15,612

[1] Assumes that 16.7% of the egg-punctured fruit will produce adults.

not applied is governed by the amount of fruit available for boll weevil development, rather than by the net increase potential of the pests.

It should be kept in mind that we are dealing with representative populations. Some acreages of cotton may have overwintered populations up to 1,000 or more. Boll weevils will overlap generations, and the percentage of squares and bolls damaged will steadily increase as the season progresses. The reason that the percentage of punctured squares does not increase more rapidly is due in large measure to the remarkedly fast and abundant fruiting characteristics of cotton which keep fruit production ahead of the growing boll weevil population. However, a population of the type depicted would eventually destroy all late-fruiting forms. But there are likely to be enough squares and bolls present even then to yield large numbers of developing boll weevils in generations 4 and 5 that would enter hibernation and emerge the next season. Extensive migration could be expected from the progeny produced in the third and fourth gnerations as well. Also, under conditions of high populations and limiting fruiting forms, one can expect high mortalities of the boll weevils. Even so, where hibernating conditions are favorable, the type of population depicted might produce an overwintered population of 1,000 boll weevils per acre or even more.

The average increase rate has been said to be tenfold in each generation until the population approaches maximum density. It is unlikely that the rate of increase will be of the same order each generation. However, the final size of the population would be essentially the same if the model projected variable increase rates which averaged tenfold per generation.

THE USE OF INSECTICIDES FOR THE CONTROL OF THE BOLL WEEVIL

If the boll weevil has a net increase potential of tenfold until the population becomes self-limiting because of inadequate fruiting forms for reproduction and because of other density-dependent forces, it is apparent that suppressive measures must be rather intense and exacting in order to maintain adequate control. One of the current goals in boll weevil management is to reduce populations to the lowest practical level with a minimum use of insecticides during the regular growing season. The adverse effects that boll weevil insecticides have on beneficial insects that attack *Heliothis* and other cotton pests make it imperative that long-range efforts be made to minimize the use of insecticides during the early generations. Once insecticide applications are started for boll weevil or *Heliothis* control, there is the risk that applications will have to be continued for the rest of the season. Thus, from a cotton culture standpoint it is necessary to consider control practices that affect the boll weevil as well as *Heliothis* and other cotton pests.

In all probability, routine boll weevil control with insecticides as practiced by growers is not likely to achieve more than 90% kill each application. Perhaps four applications at 5- to 7-day intervals each generation will be needed to achieve this level of control. If this is a valid estimate of the effectiveness of usual insecticide applications, we can develop a suppression model using the basic parameters and predict the type of control program based on the use of insecticides that would reduce the overwintered populations from a representative level of 200 per acre to about 20 per acre. This simulated model is shown in table 2. According to the parameters established, it would be necessary to apply insecticides in generations 2 and 3 to protect the crop, and necessary to continue insecticide treatments during generations 4 and 5 to destroy most of the diapausing boll weevils in order to expect to reduce overwintered populations averaging about 200 per acre to a level averaging about 20 per acre. It is estimated that a total of 14 insecticide applications would be required the first year to reduce a generally high boll weevil population to a generally low level.

Once a population is reduced to a level of about 20 per acre, however, it could be maintained at that level with less frequent use of insecticides. It should be possible to delay the start of insecticide treatments until generation 3 and maintain a generally low population level by making about 10 insecticide applications each season during generations 3–5. The simulated suppression model based on a starting population of 20 boll weevils per acre is shown in table 3. The assumption is made that *all* cotton in a community will be treated as needed. Such a program would virtually assure no losses from the boll weevil and would require less use of insecticides. Also, a delay in starting boll weevil control treatments

TABLE 2.—*Proposed in-season and diapause control program needed and results necessary in first year to reduce boll weevils to a reasonably manageable level when overwintered population averages 200/acre*

Generation	No. weevils/acre		No. squares and bolls	Insecticide treatments		Egg punctures		Percent diapausing boll weevils	No. weevil progeny	
	Reproducing	Diapausing		No.	Percent control	Percent	No.		Reproducing	Diapausing
1	200	0	200,000	0	..	6	12,000	0	2,000	0
2	2,000	0	400,000	4	90	3	12,000	0	2,000	0
3	2,000	0	200,000	4	90	6	12,000	25	1,500	500
[1]4	1,500	500	100,000			9	9,000	75	375	1,125
[1]5	.....	1,125	....	6	90	..	.....	..	.....	.....

[1] 6 treatments during generations 4 and 5 estimated to kill 90% of diapausing boll weevils, reducing the potential hibernating population to 162/acre. Assuming 12% will survive, the starting population would average 20/acre in the next season.

TABLE 3.—*Proposed in-season and diapause control program needed and results necessary to maintain reasonable management of boll weevils when the overwintered population averages 20/acre*

Generation	No. weevils/acre		No. squares and bolls	Insecticide treatments		Egg punctures		Percent diapausing boll weevils	No. weevil progeny[1]	
	Reproducing	Diapausing		No.	Percent control	Percent	No.		Reproducing	Diapausing
1	20	0	200,000	0	..	0.6	1,200	0	200	0
2	200	0	400,000	0	..	3.0	12,000	0	2,000	0
3	2,000	0	200,000	4	90	6.0	12,000	25	1,500	500
[1]4	2,000	500	100,000			9.0	9,000	75	375	1,125
[1]5	.....	1,125	....	6	90	...	.....	..	.....	.....

[1] 6 treatments during generations 4 and 5 estimated to kill 90% of diapausing boll weevils, reducing the potential hibernating population to 162/acre. Assuming a survival of 12%, the starting population the next year would again average 20/acre.

TABLE 4.—*Estimated growth of a boll weevil population and infestation rates if no control measures are applied when the starting population averages 20/acre*

Generation	No. weevils per acre		No. squares and bolls	Egg punctures		Percent diapausing boll weevils	No. weevil progeny	
	Reproducing	Diapausing		Percent	No.		Reproducing	Diapausing
1	20	0	200,000	0.6	1,200	0	200	0
2	200	0	400,000	3.0	12,000	0	2,000	0
3	2,000	0	200,000	60.0	120,000	25	15,000	5,000
4	15,000	5,000	100,000	100.0	100,000	75	4,175	12,500
5	4,175	12,500	....	.....	....	...	.....	......

would delay possible *Heliothis* outbreaks by one boll weevil generation. Therefore, we can conclude that such a program would be much more acceptable than uncoordinated boll weevil control practices that allow high starting populations each season.

The model in table 3 indicates, however, that the use of insecticides late in the growing season as needed and continuing as a diapause control program in the fall offers little hope of resolving the boll weevil problem in an acceptable manner. Even a well-organized and reasonably good boll weevil management program in which virtually 100% of the growers participate would still require a year-to-year fight with insecticides in the more seriously infested boll weevil areas. The ecological disturbance to beneficial insects and the risk of the development of insecticide-resistant strains of the boll weevil would continue.

A major problem, however, in dealing with the boll weevil is the maintenance of a good management program based on voluntary participation by growers. Even in the most progressive cotton-growing areas, it is unlikely that more than 90% of the growers in a community will treat the cotton in a manner that will result in 90% control each generation through generations 3–5, even if the average overwintered population had previously been reduced to a low level of 20 per acre. Table 3 has shown how a population would develop and shown the type of insecticide treatments necessary in order to maintain a low overwintered population each year, even with full participation by growers.

Table 4 shows the number of boll weevils that would develop per acre, based on the assumed increase rate of tenfold per generation, if no treatments were applied during the season and the starting population were as low as 20 per acre. The calculations indicate that 17,500 diapausing boll weevils could be expected to develop on each acre of untreated cotton by season's end. This exceeds the level projected for an uncontrolled population that starts with 200 per acre. This may seem unrealistic, but there is a sound biological basis for this conclusion. The higher starting populations would become self-limiting because of inadequate fruiting forms during the diapause period. The lower starting population would have more fruit in which to develop during generations 4 and 5, when most of the diapausing boll weevils develop.

If we make the assumption that in a program based on voluntary participation by growers, the equivalent of 10% of the cotton acreage in a community will not be treated, we can clearly indicate the effect of such neglect on overwintered boll weevil populations in the community. This is indicated in table 5. The calculations show that more than 100 times as many potential hibernating boll weevils would develop on each acre of untreated cotton than on each acre of treated cotton. Or, stated another way, there would be more than 10 times as many overwintered boll weevils in a community if 10% of the cotton were not managed for boll weevil control than if all cotton were properly managed. If a boll weevil management program as proposed in table 3 were instituted, but the equivalent of 10% of the cotton received no treatments, the overwintered population would average about 190 boll weevils per acre instead of an average of 20 per acre, which is the population level proposed as necessary to reduce the need for in-season applications to a minimum. In all probability, control measures would have to be applied on most acreage one generation in advance of the time such treatments would be necessary if the average starting population were as low as 20 per acre. Not only would this be more costly, but more insecticides would be required and secondary pest problems would be intensified. Also, resistant strains would likely develop sooner under such uncoordinated control practices.

For some years I have advocated the total population suppression approach to the management of key insect pests (Knipling 1960, 1966). This view was based on the difference in the number of insects that can develop during a

TABLE 5.—*Estimated number of overwintered boll weevils/acre produced on treated and untreated cotton, starting with 20 boll weevils/acre*

Generation	No. diapausing weevils surviving/acre	
	Treated acreage	Untreated acreage
1	0	0
2	0	0
3	[1]50	5,000
4 and 5	[1]112	12,500
Totals	162	17,500

[1] Treatments in generations 3–5.

series of generations when the total population, versus only a portion of the population, is suppressed. We know enough about the dynamics of all of our major pests to accept this as a fundamental principle of insect population suppression, but I know of no pest for which the application of the total population suppression concept is so important and so urgently needed as the boll weevil.

For 50 years the boll weevil has been controlled in a haphazard manner on a relatively small part of the total cotton acreage, but we as entomologists have done very little to emphasize the severe penalty that all growers pay because of the neglect of a few. Moreover, we have not emphasized enough the hazards and the added costs of the greater amount of insecticides used in our southern agricultural environment each year because of such neglect by a small proportion of the growers.

It is my view that it is time for all pest management specialists, administrators, and cotton industry representatives who have the responsibility for outlining pest-management procedures to take a good look and decide what the goal should be in efforts to provide a better and more acceptable solution to the boll weevil and the *Heliothis* problems. The two types of pests must be dealt with jointly so long as broad-spectrum insecticides are required for boll weevil control.

Consideration should be given to two possible solutions: (1) The elimination of the boll weevil where it is feasible and maintenance of continuous suppression in situations where elimination is not feasible. (2) Institution and maintenance of subeconomic populations of the boll weevil beltwide, employing methods of suppression that require no insecticides or the absolute minimum use of insecticides during the regular growing season. In my view, these two alternatives now offer the only hope for a satisfactory solution to both the boll weevil and *Heliothis* problems.

MINIMUM BOLL WEEVIL POPULATIONS THAT WILL OBVIATE THE NEED FOR IN-SEASON INSECTICIDE APPLICATIONS

In view of the great increase potential of the boll weevil, I estimate that it will be necessary to reduce overwintered populations to a very low level each year in order to avoid the necessity of in-season applications of insecticides. Table 6 projects the growth of a population starting with 10 weevils per acre, based on parameters previously outlined. It is noted that economic damage to the crop would likely be avoided because the percentage of egg punctures is low through the third generation. However, it should also be noted that even such a low starting population would grow to the estimated size of 10,000 boll weevils per acre by the fourth and fifth generations. This would mean a very high overwintered population the next year unless strong suppressive measures were taken after the cotton crop was made.

TABLE 6.—*Estimated minimum overwintered population of the boll weevil necessary to provide reasonable assurance of no need for in-season control*

Generation	No. weevils per acre	No. fruiting forms	Egg punctures Percent	Egg punctures No.	No. weevil progeny
1	10	200,000	0.3	600	100
2	100	400,000	1.5	6,000	1,000
3	1,000	200,000	30.0	60,000	10,000

It is my conclusion that even if a population starts as low as 10 per acre, an intensive post-season suppressive effort with insecticides would have to be directed against the overwintered population each year in order to again reduce boll weevils to numbers that would make unnecessary in-season control measures during the next year.

Based on these models, the requirements for an effective boll weevil management program seem clear. First, the overwintered population must be reduced to a very low level each year. Second, whatever suppressive measures are employed, it will be necessary that they be applied to the total population. A management program based primarily on the use of insecticides, even if limited to the fall, leaves much to be desired as a solution to the boll weevil problem. Looking ahead, however, it is also my conclusion that the degree of insecticide-based suppression necessary for reasonable assurance that in-season insecticide applications will not be needed would reduce the boll weevil populations to a level that should be manageable or one which could be eliminated at relatively low cost in relation to the benefits by the use of pheromones, sterile males, or both. This will be discussed in more detail later in this report.

STRATEGIC USE OF INSECTICIDES TO ACHIEVE HIGH BOLL WEEVIL SUPPRESSION

A number of years ago, simulated boll weevil suppression models were developed to calculate the effect of different insecticide spray schedules directed against the last reproducing generation and the diapausing boll weevils. The purpose of the study was to propose spray schedules that would reduce overwintered boll weevil populations to a level that could be managed the next season by releasing sterile males. This was probably the first effort to use modeling procedures based on biomathematical parameters, to calculate the effect of different spray schedules for suppressing the boll weevil. The results of the simulated suppression strategies were put to test by regulatory agencies in the Presidio and High Plains area of Texas. Details of the procedure used and results of this study have been published (Knipling 1968), and will not be discussed here. However, the calculations showed that if four sprays scheduled to suppress diapausing boll weevils, as suggested by Brazzel et al. (1961) would achieve of the order of 90% suppression, then a total of seven sprays, properly timed to both minimize reproduction and kill diapausing boll weevils, could be expected to achieve of the order of 99.7% suppression. The meaning of percentages can be deceiving. If these percentage figures are regarded casually, one might conclude that 9.7% difference in kill is not very significant. Yet, in terms of survivors that can attack the crop the next year, this would mean that if the population controlled consists of 1,000 boll weevils, 90% kill would leave 100 survivors, whereas, 99.7% would leave only three survivors. Field observations by Fye et al. (1968) and Adkisson et al. (1966) indicated that the results of the simulated suppression models were highly predictive of actual results that could be obtained in operational programs.

From the standpoint of the dynamics of the boll weevil, maximum impact of insecticide treatments is best achieved by directing suppressive efforts against the overwintered generation. There are sound reasons for this based on the biology, dynamics, and behavior of the boll weevil. During the regular reproducing generations, the survivors are capable of reproduction at a high rate. Thus, one must take into account and attempt to counter the immediate increase potential of the individuals not killed. On the other hand, if strong suppressive measures are directed against the last reproducing generation, the number of diapausing boll weevils that can emerge will be limited. Then, if suppressive measures are continued against the reduced diapausing population, the degree of kill will be translated into the degree of reduction in the boll weevils that can overwinter because they cannot reproduce. In addition, the survivors can be expected to suffer the high mortality common to insects during winter. Thus, the insecticide applications have maximum impact on the size of a population at a time when there is also a high natural mortality.

Table 7 shows the relative size of the overwintered populations on one acre for an uncontrolled population after a good in-season program by growers that has kept square infestations below 10%. The table also shows the num-

TABLE 7.—*Number of overwintered boll weevils/acre on untreated cotton and on cotton receiving thorough applications of insecticides that kill 95% of the last reproducing generation and 95% of the diapausing progeny*[1]

Generation or period	No. weevils/acre	
	Uncontrolled population	Controlled population
Last reproducing generation	1,000×10=10,000	1,000−95%=50×10=500
Diapausing boll weevils	10,000	500−95%=25
Hibernation period	10,000−90%=1,000	25−90%=2.5

[1] Assumes prior in-season control by growers that limits egg punctures to 10%. Reproducing boll weevils increase tenfold per generation. Natural mortality of 90% is assumed for both populations.

ber of overwintered boll weevils that would survive if insecticides were applied thoroughly so as to reduce reproduction by the last reproducing generation by 95% and then continued so as to kill 95% of the diapausing progeny that do develop. (It is assumed that applications will start following the last application by the grower.) In the absence of control it is estimated that the last reproducing generation would consist of 1,000 reproducing boll weevils per acre and that they would produce 10,000 diapausing boll weevils.

About four thorough applications of insecticides at about 5-day intervals immediately following the last grower application should reduce reproduction in a population by 95%. Also, a similar degree of kill of the remaining diapausing boll weevils should be achieved by making four applications of insecticides at about 10- to 14-day intervals until season's end. Therefore, there is reason to have confidence in the predicted small number of overwintered survivors following a well-executed reproduction-diapause program. In the second year of the Pilot Boll Weevil Eradication Experiment (PBWEE), when both a good in-season program and a thorough reproduction-diapause program were carried out, there is little question that the overwintered population was reduced below the level calculated for the model. Thus, there is every reason to regard the model as highly predictive of actual suppression that can be obtained by the strategic use of insecticides as outlined.

It should be pointed out that a comparable degree of boll weevil suppression would not be obtained if insecticides were applied to reproducing generations during the regular growing season. The model in table 8 shows the impact of 95% suppression of reproduction each generation starting with an overwintered boll weevil population of 1,000 per acre. What this shows is that there would be more boll weevils per acre remaining after applying 16 applications during four generations during the growing season, than 8 applications made at the strategic last reproducing and diapausing period.

Table 9 shows what we might expect from insecticide applications applied to a population reduced to two boll weevils per acre, or 200 on 100 acres. Note that 95% suppression of reproduction until the fourth generation and probably 16 insecticide applications during in-season would be necessary. Theoretical elimination is difficult because of the net increase rate of tenfold for the 5% survivors each generation. Thus, aside from the adverse ecological effects of insecticide applications during the growing season, the growing season is not a strategic time for maximum suppression by insecticide applications when related to the dynamics of the boll weevil.

In view of the importance of boll weevil control in the fall, either for purposes of management or as a major component in an eradication effort, I have calculated the number of overwintered boll weevils to expect following various degrees of thoroughness in the application of control measures directed against the last reproductive and the diapausing generations. The results are shown in table 10.

It should be stressed that every component used in an elimination program, or even in a good management program, should have backup suppressive measures to make up for interruptions in a program because of adverse weather or other causes. If one or two applications of insecticides should be missed when applied to the reproducing generation, it should be possible to largely correct for this by closing the spray intervals during the emergence period of the diapausing boll wee-

TABLE 8.—*Effect of insecticides on the trend of a boll weevil population when thorough applications are started against an overwintered population of 1,000/acre*

Generation	No. weevils/acre	Level of suppression (percent)	No. reproducing survivors	Increase rate	No. progeny
1	1,000	95	50.0	10-fold	500.0
2	500	95	25.0	10-fold	250.0
3	250	95	12.5	10-fold	125.0
4	125	95	6.25	10-fold	62.5

TABLE 9.—*The estimated trend of a low level boll weevil population (2/acre) on 100 acres when subjected to insecticide treatments that reduce reproduction by 95%*

Generation	No. weevils on 100 acres	Kill with insecticides (percent)	No. weevils reproducing	No. progeny produced
1	200	95	10.0	100
2	100	95	5.0	50
3	50	95	2.5	25
4	25	95	<2.0	0

TABLE 10.—*Effect of different levels of control of the last reproducing and diapausing generations on the overwintered boll weevil population*[1]

1. No control:
   $N_o = N_r(R_r)(S_d)$
   $N_o = 1{,}000(10)(0.10) = 1{,}000/\text{acre}$
2. 80% control:
   $N_o = N_r(S_{ri})(R_r)(S_{di})(S_d)$
   $N_o = 1{,}000(0.20)(10)(0.20)(0.10) = 40/\text{acre}$
3. 90% control:
   $N_o = 1{,}000(0.10)(10)(0.10)(0.10) = 10/\text{acre}$
4. 95% control:
   $N_o = 1{,}000(0.05)(10)(0.05)(0.10) = 2.5/\text{acre}$
5. 98% control:
   $N_o = 1{,}000(0.02(10)(0.02)(0.10) = 0.4/\text{acre}$

[1] In the models, N_0 = number overwintered weevils/acre; N_r = number weevils present that could reproduce; R_r = net increase rate of weevils that reproduce; S_d = normal survival rate of diapausing weevils; S_{ri} = survival rate of reproducing weevils subjected to control; S_{di} = survival rate of diapausing weevils subjected to control.

vils. It would also be possible to make up for interrupted spray schedules in the fall by making one or two insecticide applications after boll weevils emerge from hibernation the next spring. Boll weevil capture rates in pheromone traps could serve as guides for such spring applications.

ROLE OF STERILE MALES FOR BOLL WEEVIL SUPPRESSION

It has long been recognized that the sterile-male technique could play a vital role in boll weevil suppression. The manner in which sterile male boll weevils might or might not be useful in integrated programs for boll weevil elimination has previously been discussed (Knipling 1964), and will not be repeated here. However, it seems desirable to show how important this method of suppression can be. The basic model, already shown in table 9, can demonstrate the potential advantage of sterile males over insecticides as a final elimination technique. This does not take into account the ecological advantages of employing sterile males rather than insecticides to reduce populations during the growing season. If a population has been reduced to a level of about two boll weevils per acre, which should be attained by a proper in-season program and a rigid reproduction-diapause spray schedule, as already discussed, we propose the release of 100 sterile males per acre each generation. The Boll Weevil Research Laboratory and a number of other U.S. Department of Agriculture laboratories have devoted a great deal of research to the development of rearing and sterilizing procedures. This work has been discussed by T. B. Davich and will not be reviewed here.

In estimating the impact of sterile insects by the modeling procedure, it has been my practice to allow for substantial loss of competitiveness of the released insects because of damage attributable to sterilization and because of behavioral changes that seem to occur in laboratory-reared insects. Therefore, the assumption is made that the sterile males will be only 25% competitive. A tenfold net increase potential will be assumed as in previous models. Table 11 projects the effects of the release of sterile insects on 100 acres of cotton having an overwintered surviving population of 200 boll weevils of both sexes.

The theoretical results are very impressive. Whereas it was estimated that at least 16 insecticide treatments applied during four generations would be required to eliminate such low populations by the use of insecticides, the release of a total of 200 sterile males per acre should accomplish elimination in two generations. Even if it cost $10 per 1,000 to rear, sterilize, and separate sexes, the cost of the sterile-male procedure would be less than insecticides. On this basis, the cost of 200 sterile males per acre would be only $2 per acre. The cost of releasing the insects would be the major cost.

In the PBWEE, the ratio of sterile-to-fertile males was of the order of 100 to 1 in the core zone.[2] There is every indication that the sterile males performed their mission even though the quality of the boll weevils released was generally low.

While improvements in sterilization, rearing, and handling are needed, and there is little doubt that marked improvements can and are being made, there is no question that the release of sterile males can perform a vital function in boll weevil elimination programs. When populations reach the point that the presence or absence of boll weevils cannot readily be determined by available detection methods, it may be much less costly to routinely release a minimum number of sterile males as a security measure than to devote a major effort to detection.

[2] See Lloyd et al., "Release of Sterile Male Boll Weevils in the Pilot Boll Weevil Eradication Experiment in 1972–73," this volume.

The possibility of employing sterile boll weevils as a suppression system in boll weevil management programs should not be ruled out. We earlier expressed the view that an overwintered population would have to be reduced to about 10 boll weevils per acre to have reasonable assurance of growing a cotton crop without the need for in-season insecticide applications. However, insecticides would have to be employed intensively during generations 4 and 5 to again reduce overwintered populations to a level of 10 per acre. Such measures would have to be used year after year. Table 12 projects the theoretical impact of sterile-male and female releases at the rate of 200 of each sex per acre for three generations. As before, the released boll weevils are assumed to be 25% competitive.

Based on the calculations in the table, the sterile boll weevil releases would maintain a stable population in generations 1–3. The rate of increase in generation 4, even if no releases were made, would not be great enough to maintain the overwintered population at the original level. It seems self-evident, however, that if a population could be suppressed as shown, sterile-

TABLE 11.—*The estimated effect of the release of 100 sterile male boll weevils/acre each generation after a population is reduced to 2/acre on 100 acres of cotton*[1]

Generation	No. weevils: Native	No. weevils: Sterile males	Effective S:F ratio	No. females reproducing	No. normal progeny
1	100 ♂ + 100 ♀	10,000	25:1	4	80
2	40 ♂ + 40 ♀	10,000	62:1	<1	0

[1]Assumes tenfold increase for weevils that reproduce. The effective sterile-to-fertile (S:F) ratio is assumed to be 25% of the actual ratio.

TABLE 12.—*The estimated effect of sterile boll weevil releases at the rate of 200 males and 200 females/acre on 100 acres during the first three generations when the natural overwintered population is reduced to five males and five females/acre*[1]

Generation	No. weevils: Native	No. weevils: Sterile	Effective S:F ratio	No. females reproducing	No. normal progeny
1	1,000	40,000	9:1	50	1,000
2	1,000	40,000	9:1	50	1,000
3	1,000	40,000	9:1	50	1,000
4	1,000	0	...	500	10,000

[1] It is assumed that reproducing females produce 20 progeny each. The effective sterile-to-fertile (S:F) is assumed to be approximately 25% of the actual ratio. Progeny produced in generation 4 are assumed to diapause. Ten percent survival would result in 1,000 boll weevils on 100 acres, or 10/acre.

male releases should continue in generation 4, which would mean virtual absence of boll weevils the next season. However, the point here is to indicate how sterile males rather than insecticides could be used to maintain subeconomic populations.

While variable population densities as they generally occur in the field will no doubt require supplemental suppressive measures on some cotton, the models shown convey the principles of boll weevil management by the release of sterile males. Any good management program, whether it be based on the use of sterile males, pheromones, traps, insecticide applications, or any other technique will require constant monitoring. Supplemental suppressive measures will have to be applied where and when necessary. As previously noted, it probably will be necessary to make 6 to 8 insecticide applications in the fall at a cost of perhaps $12 to $16 per acre to maintain boll weevil populations at a level of 10 or less per acre. Sterilization procedures for both sexes would not have to be as exacting for management as for elimination. There is good reason to believe that the estimated 1,200 sterile boll weevils of both sexes required each season would cost less for rearing and release than the application of insecticides necessary to achieve the same results. However, the greatest benefit would be to control the pest by a completely selective method which would make it possible for natural biological agents to achieve normal suppression of *Heliothis* species. It should be kept in mind that while the use of insecticides restricted to the fall may greatly minimize the effect of insecticides on beneficial insect complexes, there is still every reason to regard such treatments as ecologically undesirable.

THE POTENTIAL ROLE OF GRANDLURE FOR BOLL WEEVIL DETECTION AND SUPPRESSION

The identification and synthesis of the boll weevil sex pheromone complex grandlure (Tumlinson et al. 1971), and its demonstrated biological activity for the detection and suppression of the boll weevil (Hardee et al. 1971), promise to be one of the most important developments in boll weevil research since the discovery and development of boll weevil insecticides.

There is still much we do not know about grandlure and other insect sex pheromones and about how useful they will prove to be both for suppression and detection. However, based on progress made on the boll weevil, as well as on other insects, I feel that the potential for using grandlure for boll weevil elimination or management is very great. My confidence is based in large measure on the results of many simulated models that have been established and analyzed to estimate the potential for boll weevil suppression and detection by the use of the pheromone in different ways. Even before grandlure was synthesized, models were established to appraise the potential for using males in traps as a means of suppressing low-level population (Knipling and McGuire 1966).

The theory originally advanced that the efficiency of boll weevil pheromones and other insect sex pheromones used in traps will be influenced by the density of the target pest has been confirmed in principle for the boll weevil and other insects (Lloyd et al. 1972, Roelofs et al. 1970). Thus, all models take into account competition between pheromone-baited traps and males that produce the natural pheromone. The use of the pheromones in traps placed around cottonfields or in trap crops as employed in the pilot experiment will not be discussed here, but I have had particular interest in the use of grandlure-baited traps placed inside cottonfields for boll weevil suppression and for boll weevil detection along lines recently reported by Mitchell and Hardee (1974).

My preliminary theoretical study of the potential value of in-field traps for the suppression and detection of low-level boll weevil populations was distributed to a few investigators. The title of the paper is "An Analysis of the Potential Role of Grandlure Baited Traps Inside Cotton Fields for the Suppression and Detection of Boll Weevil Populations" (Oct. 5, 1973, 61 pp., mimeo).

The characteristics of grandlure as an aggregating attractant for both sexes, as well as a sex attractant for females seeking males for mating, are matters of great potential importance. It is difficult to establish models to estimate the efficiency of baited traps or baited trap-crop plantings against overwintered boll weevils because there is no way of knowing the degree of competition that may exist between the males before they begin producing the natural pheromone and the synthetic pheromones placed in traps or trap plantings. It seems reasonable to assume that the cotton plants are also very much involved in the competition between traps and pheromone-producing males. The degree of efficiency of currently employed traps in actual capture of boll weevils that respond is not known. Therefore, it is necessary to make certain assumptions in order to estimate the potential of pheromone suppression systems. From the observations of many investigators it is known, however, that the pheromone is a powerful attractant for both sexes of the boll weevils emerging from hibernation, and the recent report by Mitchell and Hardee presenting preliminary results with in-field traps indicates that the pheromone is a powerful attractant for unmated females emerging in cottonfields. We also know that females emerging in cottonfields must find males and mate before they can reproduce. Therefore, there is no question that the pheromone has great attractant power. Its ultimate effectiveness will be a matter of developing its potential for boll weevil control. The use of theoretical models and assumed parameters may be an important aid in developing this potential.

USE OF IN-FIELD TRAPS TO CONTROL OVERWINTERED BOLL WEEVILS

It is my view that the density of the natural boll weevil population will determine the degree of effectiveness of in-field traps baited with grandlure, whether we are dealing with boll weevils emerging from hibernation after fruiting begins, or boll weevils emerging in cottonfields during the F_1 and subsequent generations. However, the degree to which unmated females emerging in cottonfields will be attracted to traps in all probability will be governed entirely by the density of the natural male population and the competition they give to the traps for the attraction of the females.

Since both sexes of overwintered boll weevils respond to the pheromone, whereas there are indications that only unmated females in the F_1 and F_2 generations respond, it is necessary to establish different parameters in order to estimate the potential usefulness of in-field traps.

The assumption will be made that a trap baited with grandlure will have attractant power for unmated females that is equal to the attractant power of feeding males. While this has not been established, data are available which indicate that a pheromone-baited trap will capture about as many boll weevils of both sexes as a trap baited with four males feeding on cotton squares. It is also assumed that in-field traps will be available that capture or destroy the females when they respond to the traps. It may seem overly optimistic to assume that traps will be equal to feeding males in attracting females. On the other hand, it is also possible that pheromone-baited traps could be more powerful than feeding males in attracting females. There are already broad indications that pheromones for a number of insect species, when used in traps, will capture more males than unmated females placed in similar traps. The estimated effect of traps in capturing female boll weevils will be based on one mating only for females. It is known, however, that some females seek males for second or even more matings. This could be a very strong additional suppression factor that is not provided for in the models, and which could offset assumptions that may be too optimistic. It is possible, too, that the pheromone emanating from traps will result in confusion of females and either prevent or delay mate-finding at very low densities.

The estimated effect of traps will be considered only for low level populations. The potential value of in-field traps will first be considered for overwintered populations that have been reduced to 10 per acre. There is every reason to believe that this level of suppression can be attained in any area of the Cotton Belt, and in some areas, the population may not exceed this number without prior suppression. It was suggested earlier that 10 boll weevils per acre would be the maximum which would assure no need for insecticides during the regular growing season. Thus, on the premise that eventually it will be necessary to reduce populations to such a low level for purposes of good boll weevil management, estimates will be made of the potential for continuous management by the use of in-field traps. It is proposed that traps be used at the rate of 10 per acre. This would mean that the distance between traps will be about 66 ft. The spatial relationship of traps to competing males for the attraction of females will undoubtedly have an important influence on the effectiveness of in-field traps. Thus, the maximum number of traps that would be practical to use may be one of the most important factors in the efficiency of the trapping system. An arbitrary assumption is made that only half the overwintered males will be captured by the traps as they enter the cottonfields. Those not trapped will become competitive with the traps for the attraction of the females that enter the fields. The population will occur on 100 acres of cotton in which 1,000 traps are in operation. Both males and females will enter the 100-acre field at the rate of 25 males and 25 females per day on 20 different days. This will account for the total population of 500 males and 500 females on 100 acres of cotton. It is well recognized that boll weevils do not emerge from hibernation and enter fields at a uniform rate; however, the use of averages will make the model more simple and should not substantially affect the final result.

On the basis of the assumptions outlined, the calculated degree of control of the females is shown in table 13.

The ratio of traps to feeding males starts at a level of 80:1 on day 1. This would mean that only one of 81 females would be expected to mate with a competing male and 80 would be captured. On the basis of the presence of only 25 females on day 1, this would mean that the female mating rate would be 0.3. However, as the number of competing males increases, the ratio of the attractant power of the traps to that of the males diminishes. No allowance is made for natural mortality, so by the time all males have entered the field, the ratio of traps to competing males would be only 3.8:1. This would mean that 5.2 of the 25 females entering the field on the last day would be expected to mate ($1/4.8 \times 25 = 5.2$).

By the time emergence of overwintered boll weevils is completed, a total of 57 females would mate and 443 would be captured. This would compare with 500 mated females for an uncontrolled population. The percentage control would be 88.5%, calculated as follows:

$$100 - [(57.4 \times 100)/500] = 100 - 11.5 = 88.5.$$

If the simulated suppression model is reasonably predictive of actual results to be expected from in-field traps, this would provide an effective and a desirable means of control. Based on 20 progeny from each mated female, the F_1 population would be 11.4 per acre. This would represent a slight increase over the overwintered population. The continued use of in-field traps during the F_1 generation should exert considerable suppression, but the behavior of the boll weevils during egg deposition is such that emerging F_1 progeny in all probability would be highly concentrated, and the in-field traps would be substantially less effective. When boll weevils enter cottonfields from hibernation, the pheromone traps should prevent the usual aggregating behavior of the males and females. Such dispersion of boll weevils emerging in the F_1 generation is not likely to prevail. While no model will be presented, if females only respond to traps during the F_1 emergence period, the overall trap-to-male ratio would be less than 2:1 during the F_1 generation. However, the spatial relationship of the males and females to the traps would likely become a major factor in trap-capture efficiency. If we assume the emergence of six males and six

TABLE 13.—*The estimated number of female boll weevils that will be captured in 1,000 in-field traps operating in 100 acres of cotton*[1]

Day	No. feeding males	Ratio of traps to males	No. females Captured	No. females Mating
1	12.5	80:1	24.7	0.3
2	25.0	40:1	24.4	.6
3	37.0	26:1	24.1	.9
4	50.0	20:1	23.8	1.2
5	62.0	16:1	23.5	1.5
6	75.0	13.3:1	23.3	1.7
7	87.0	11.4:1	23.0	2.0
8	100.0	10:1	22.7	2.3
9	112.0	8.8:1	22.5	2.5
10	125.0	8:1	22.2	2.8
11	137.0	7.3:1	22.0	3.0
12	150.0	66:1	21.7	3.3
13	162.0	6.1:1	21.5	3.5
14	175.0	5.7:1	21.3	3.7
15	200.0	5:1	20.9	4.1
16	212.0	4.7:1	20.6	4.4
17	225.0	4.4:1	20.4	4.6
18	237.0	4.2:1	20.2	4.8
19	250.0	4:1	20.0	5.0
20	262.0	3.8:1	19.8	5.2
Total				57.4

[1] Males and females are assumed to enter fields at the rate of 25/day for 20 days. Half the males are assumed to escape capture and begin producing pheromones in competition with the traps. Expected females mating in an uncontrolled population=500; in controlled population=57. Percent control=88.5.

females per acre in the infested areas during a 20-day period, and if the emerging boll weevils tend to be concentrated, the degree of control would probably not exceed 75%. While theoretical suppression of reproduction by 88% for the first, or overwintered generation, and 75% for second, or F_1 generation, would have a major impact on the seasonal growth of the population, the traps alone may not obviate the need for some insecticide applications during the F_4 and F_5 generations in order to again reduce the overwintered population to a level of 10 per acre. Nevertheless, the model suggests that pheromone traps should come close to maintaining subeconomic populations in most boll weevil areas without the need for insecticide applications if the populations are once brought down to a level of about 10 boll weevils per acre.

I have used an overwintered population of 10 boll weevils per acre to calculate the potential value of in-field traps. If the population has been reduced to a level of about two per acre, which seems readily possible by the use of a thorough reproduction-diapause spray program, the in-field traps alone, based on the parameters, should achieve of the order of 98% capture of the females, which would mean that only about two reproducing females would occur on 100 acres.

APPLICATIONS OF INSECTICIDES SUPERIMPOSED ON IN-FIELD TRAPS FOR THE SUPPRESSION OF OVERWINTERED BOLL WEEVILS

Based on the theory advanced concerning the mechanism of suppression achieved by in-field traps, one can postulate that insecticide applications superimposed on the use of traps would provide a very powerful added suppression component. While there are serious objections to the use of any insecticides early in the season, such a combined attack for 1 year might be given serious consideration as a very effective and low-cost method of achieving elimination of populations. The insecticide applications would produce two effects. They would reduce male competition, and thus increase the action of the pheromone traps. They would also contribute to overall suppression by killing most of the mated females escaping capture before they can deposit the usual number of eggs.

TABLE 14.—*The theoretical effect of insecticide applications superimposed on the action of 1,000 in-field traps for boll weevil suppression on 100 acres of cotton*[1]

Day	No. feeding males	Ratio of traps to males	Females mating
1	12.5	80:1	0.3
2	25.0	40:1	.6
3	37.0	26:1	.9
4	50.0	20:1	1.2
5	62.0	16:1	1.5
6	75.0	13.3:1	1.7
[2]7	20.0	50:1	.5
8	32.0	31:1	.8
9	45.0	22:1	1.1
10	57.0	17.6:1	1.4
11	70.0	14.3:1	1.7
12	82.0	12.2:1	1.9
13	95.0	10.5:1	2.2
[2]14	22.0	45.5:1	.5
15	34.0	30:1	.8
16	47.0	21.3:1	1.1
17	60.0	14:1	1.4
18	72.0	11.8:1	1.7
19	85.0	11.8:1	1.9
20	97.0	10.4:1	2.2
Total			25.4

[1] See text for parameters. Females assumed to enter fields at rate of 25/day for 20 days. 25.4 mated females expected in treated area, 500 in untreated area. Theoretical control attributable to pheromone traps = 95%.

[2] Insecticide applications.

Table 14 projects the effect of insecticide applications superimposed on day 7 and day 14 on the action of the pheromone traps. It is assumed that 90% of the males and females that have escaped capture will be killed each treatment. This, in effect, would reduce the competition of the feeding males and make the traps more effective for the capture of females. Based on the calculations, only 25 females would be successful in mating. This would mean 95% control as a result of the pheromone traps. Theoretically, it would be necessary to operate 20 traps per acre, or perhaps slightly more, to achieve 95% control with traps alone. In effect, therefore, the insecticide applications would potentiate the action of the pheromone traps. In addition, however, the insecticide applications would kill a substantial number of the females that were successful in mating. On the basis of 90% kill of females each treatment, it is estimated that two insecticide applications would reduce the reproductive capability of the mated females by 65%. Thus, suppression of 95% due to the traps and suppression of 65% due to the insecticide applications would aggregate 98.25% control. On this basis, the equivalent of only nine females would reproduce on 100 acres or less than one on 10 acres. Such reduction should make the use of in-field traps alone sufficiently effective during the F_1 generation to virtually eliminate the population.

One additional insecticide application would make the traps even more effective. A model will not be presented, but if insecticides were applied on the 5th, 10th, and 15th days, it is estimated that the effectiveness of the pheromone traps would increase to 97.6% or the equivalent of about 40 traps alone. Also, it is estimated that three insecticide applications would reduce reproduction of the mated females by 75%. The aggregate effect in such case would be 99.4%. This would mean that the equivalent of only three females would be successful in reproducing on 100 acres. The use of insecticides would have another important effect. Most of the few females that mated would be killed before they could deposit many eggs. Consequently, there would be relatively few F_1 progeny that would be highly concentrated, which would increase the efficiency of the pheromone traps during the F_2 emergence period.

Four insecticide applications superimposed on the use of the pheromone traps would virtually assure complete suppression of reproduction. If applications were made on the 5th, 10th, 15th, and 20th day, this would not add further to the action of the traps. However, the additional insecticide applications would add greatly to the action of the insecticide component. It is estimated that suppressive action due to the traps would remain at 97.6% and suppression due to the insecticides would increase to about 95%. The combined action would be 99.89%. This would mean that reproduction by females would be reduced to less than one (actually 0.55) on 100 acres.

Table 15 summarizes the estimated action of in-field traps alone and that of the integrated systems based on the above estimates. If the projected effects are reasonably correct, the two control techniques employed simultaneously could provide a very powerful method of boll weevil elimination. The use of insecticides early in the season would be objectionable, but if the combined action of the traps and insecticide treatments had the results postulated, a boll weevil management program could be converted to an elimination program at a cost that probably would be less than the cost of management each year.

TABLE 15.—*Summary of the theoretical effect on reproduction of a low-level overwintered boll weevil population subjected to simultaneous operation of 10 in-field traps per acre and applications of insecticides*[1]

1. *No control, 500 females reproduce on 100 acres.*
2. *Traps alone:*
   57 females reproduce on 100 acres = 88.5% control.
3. *Traps plus insecticide applications on the 7th and 14th days:*
   a. Suppression due to traps = 95%.
   b. Suppression due to 2 insecticide applications = 65%.
   c. 9 females reproduce on 100 acres = 98.25% control.
4. *Traps plus insecticide applications on the 5th, 10th, and 15th days:*
   a. Suppression due to traps = 97.6%.
   b. Suppression due to 3 insecticide applications = 75%.
   c. 3 females reproduce on 100 acres = 99.4% control.
5. *Traps plus insecticide applications on the 5th, 10th, 15th, and 20th days:*
   a. Suppression due to traps = 97.6%.
   b. Suppression due to 4 insecticide applications = 95%.
   c. Less than one (0.55) female reproduces on 100 acres = 99.89% control.

[1] See text for parameters.

The models discussed well exemplify a previously stated fundamental principle of insect suppression (Knipling 1966): *The simultaneous or sequential integration of two noninteracting techniques of insect population suppression that differ in efficiency depending on the density of the target pest will be more effective than the sum of the actions of each method employed alone.*

It is my view that recognition and full development and application of this important principle of insect population suppression will have a great impact on pest management strategies for the future.

If the general magnitude of effect of in-field traps as calculated for the models could be confirmed in practice, this method of suppression would represent a great advance for boll weevil management and boll weevil elimination technology.

Time will not permit a detailed discussion of other integrated systems. Unfortunately, from a theoretical standpoint, the simultaneous use of pheromone traps and sterile-male releases would not provide a highly effective integrated system. The sterile males would compete with the traps for the attraction of unmated females and very little suppression could be expected above that which sterile males alone would achieve. Moreover, the addition of sterile males would virtually destroy the sensitivity of the traps as a detection method. Sterile males could, however, provide a useful and desirable method of eliminating widely scattered but localized incipient infestations that would be too high for in-field traps to suppress. It should also be mentioned that properly timed insecticide applications and sterile-male releases would make a powerful integrated system. Not only would the use of insecticides reduce the number of males competing with traps, but by reducing the accumulation of fertile males, insecticide applications would make the subsequent sterile male releases more effective.

USE OF GRANDLURE TO REDUCE THE RISK OF DEVELOPING INSECTICIDE-RESISTANT BOLL WEEVILS

In developing the use of grandlure as a component in boll weevil suppression systems, investigators should take into consideration the role it could play in reducing the risk of the segregation of insecticide-resistant strains of the boll weevil. In the absence of approved and effective alternate materials, resistance to currently available insecticides by the boll weevil could create a problem of major consequences to the cotton industry. This potential problem alone is strong justification for the development and use of new materials or methods of boll weevil control that have different modes of action, such as the pheromones, sterile males, or new types of insecticides, in order to reduce the chances that insecticide-resistant boll weevils will appear. The use of grandlure for suppression, whether the goal is year-to-year management or eradication, could greatly reduce the risk of resistance. However, it should be pointed out that if grandlure is used in a trap-crop system or for the purpose of concentrating the boll weevils in limited portions of cottonfields, it will still be necessary to employ available organophosphorous insecticides to destroy the insects that are attracted to the grandlure. Thus, such a method of using grandlure could be of value in substantially reducing the overall quantity of insecticides required for boll weevil control, but would not lessen the chances that insecticide-resistant strains of the insect would develop. Therefore, it seems important to continue efforts to develop trapping systems or other ways of using grandlure that will not necessitate the use of insecticides of the type now employed to control the boll weevils, or to develop materials for destroying the boll weevils attracted to the trap crops that have a different mode of action from those now used for routine control.

USE OF IN-FIELD TRAPS FOR THE DETECTION OF INCIPIENT INFESTATIONS OF THE BOLL WEEVIL

One of the most difficult problems in the conduct of insect elimination or containment programs is the detection of low-level incipient infestations. Perhaps most of the controversy in interpreting the degree of success of the PBWEE revolves around the sensitivity of methods employed to detect the presence or absence of the insect in the eradication zone. It is not surprising, nor was it unexpected, that questions should be raised as to the validity of conclusions that the feasibility of eradication was demonstrated if no boll weevils were detected by the methods employed. While E. P. Lloyd and W. P. Scott[3] have shown that the methods of detection used in the intensively surveyed fields can detect very low reproduction, the nearer the population approaches zero, the more difficult it becomes to detect the presence of infestations. This, of course, applies for any other insect. It is not possible to prove the existence of zero population.

The use of insect sex pheromone traps, in my view, offers a method of detection for insects that will completely revolutionize detection and population-assessment technology in the future, whether we are dealing with the boll weevil or any other insect for which powerful sex pheromones are available. Moreover, coupled with the

[3] See "Intensive Sampling of Twenty-five Selected Fields in Eradication and First Buffer Areas of the Pilot Boll Weevil Eradication Experiment in 1973," this volume.

advances that are being made on new technology for suppressing insects, the availability of a highly sensitive method of detecting very low-level populations should tend to change concepts of thinking on the best strategies to employ in dealing with many of our major pests.

Predictive models were developed a number of years ago, and it was postulated on theoretical grounds that sex pheromone traps would provide a highly sensitive means of detecting the presence of low populations in relation to other methods of detection for pests like *Heliothis* and the pink bollworm. For example, it was concluded that pheromone traps would have no particular advantage over light traps when the populations were moderate to high, but they should prove to be much more sensitive when the populations are low. This has been confirmed in principle by W. J. Snow et al. (1972).

I have given a great deal of attention to the potential role of in-field traps as a means of detecting the presence of low-level incipient populations of the boll weevil as they might exist in cottonfields. If the results of theoretical calculations to be discussed hold true, the use of a substantial number of in-field pheromone traps per acre will offer a method of detecting low populations that will far exceed the sensitivity of any other methods known. This will apply not only for the boll weevil but for any other insect that responds to sex pheromone traps.

In estimating the degree of sensitivity of grandlure-baited traps for boll weevil detection, the assumption is made as before that a trap will be equal to a feeding male for the attraction of an unmated female. However, it might be pointed out that the traps should still prove to be highly sensitive for detection even if they are substantially less effective than males in attracting females, or if the capture efficiency is substantially less than 100%.

The estimated degree of sensitivity for detection will be based on the ratio of traps to competing males when both are in range of detection by females seeking mates.

It is proposed that traps be used at the rate of 10 per acre and that they be examined at about 7-day intervals. While the degree of concentration of the males and females when mating occurs will obviously influence the degree of competitiveness of traps in relation to males, the calculations are based on the assumption that one acre constitutes the area of competition for males and traps, and also constitutes the area of response by unmated females.

The behavior of females in distributing eggs during their lifetime and the extent of movement of males before they begin producing pheromone, as well as the extent of movement of the females before they begin seeking mates, will unquestionably become very important factors governing the sensitivity of traps for the detection of unmated females emerging in the field. Trap spacing at about 66-ft intervals should place such traps in close range of any females seeking males. But it must be recognized that pheromone producing males and unmated females originating from a single parent may tend to be even more concentrated.

It might be pointed out that any tendency to remain concentrated could be an advantage as well as a disadvantage in dealing with the boll weevil. If females existing at very low density levels have a strong tendency to concentrate egg laying in a highly restricted area during their entire reproductive life, this would be an objectionable feature from the standpoint of detecting and suppressing the progeny by the use of traps, but this type of behavior would also make it possible to effectively destroy any incipient populations by applying control measures to a limited area when incipient infestations are detected.

The greater the tendency to remain concentrated, the more important it will be both from the standpoint of control and detection to use as many in-field traps as practical. However, based on the previously-stated assumption that each acre constitutes the area occupied by an incipient infestation, we can determine the probability of detecting different sized incipient populations when traps are used at the rate of 10 per acre.

If a single male and a single female emerge, the probability of detecting the incipient population will be 10:1 or 91%. There is no other detection method that even approaches this degree of sensitivity for detecting the presence of one female boll weevil, especially before she begins laying eggs. This degree of sensitivity would hold whether the male and female emerge in a 1-acre field or a 100-acre field. If only a female emerged, theoretical detection should be 100%.

If the incipient population consists of two males and two females that will emerge on different days, the probability of detecting the existence of the infestation would be 10:1 for the first female, and 10:2 for the second, because the ratio of traps to the first male would be 10:1 but the ratio would be 10:2 after the second male emerges and becomes competitive. Therefore, the probability of detecting the existence of the infestation by the capture of at least one of the females would be 98.5% (91%+83/100×9=98.5).

The probability of detecting an infestation increases as the size of the incipient population becomes larger. If 10 males and 10 females emerge on one acre, the chances of capturing at least one of the females would be approximately 99.999%. In other words, if one female produces 20 progeny and their emergence is limited to one acre, the odds of not detecting the infestation would be only 1 in 100,000. This would be the odds whether the incipient population occurred in fields of 1, 10, 100, or 1,000 acres. This, of course, would represent a detection probability that is fantastically high. If the infestation were limited to an area of less than one acre, the probability would of course be less. But, even if only one female from a single parent should move or emerge outside of an acre before seeking a mate, the probability of capturing the stray female would theoretically be 100% provided no males are within competitive range of the traps.

It might be overly optimistic to assume that pheromone traps will have the attractant power and capture efficiency that have been specified. On the other hand, as already stated, pheromone traps and formulations might eventually be developed that are even more competitive than a calling male. As noted previously, pheromone traps for other insects now in use or under investigation seem to be more competitive than unmated females for a number of insects.

A point that should again be emphasized is that in-field traps employed in a boll weevil elimination program could play a vital role from the standpoint of both suppression and detection of low-level populations. If very low-level infestations exist, but are widely scattered, the traps alone should provide adequate suppression. On the other hand, if the overall infestation is very low but highly concentrated, the traps would be less effective from the standpoint of suppression, but should be sufficiently effective in detecting where the incipient infestation exists to permit immediate supplemental action to suppress or eliminate the infestation. It should be a rather simple matter to destroy highly restricted incipient infestations by the use of insecticides or by the release of sterile males. Also, since the unmated females respond to the traps, the incipient infestation should be detected before or very soon after egg laying begins. Other systems of detection, such as flared square examinations, cannot show the existence of infestation until several days after oviposition has already taken place.

Based on the various parameters and conditions previously specified, table 16 summarizes the estimated effectiveness of in-field traps for suppressing and detecting very low-level incipient populations of the boll weevil. The estimates are made for different sized incipient infestations ranging from one male and one female, to 10 males and 10 females, on one acre of cotton containing 10 in-field traps.

SUMMARY AND CONCLUSIONS

The uncoordinated use of insecticides and other control measures as practiced during the past half-century will never resolve the boll weevil problem in a satisfactory manner. The pest will continue to cause high losses, and intensive use of insecticides will be required year after year, which in turn will result in a continuation of ecological disturbances that intensify bollworm, budworm, and other pest problems. Two alternatives for a more acceptable solution to these problems should be given serious consideration by those responsible for dealing with them.

TABLE 16.—*The estimated efficiency of in-field traps baited with grandlure for the control and detection of low-level boll weevil populations emerging in cottonfields over a period of time*

1. *1 male and 1 female emerging/acre:*
   Theoretical control=91%.
   The probability of detection=91%.
2. *2 males and 2 females emerging/acre:*
   Theoretical control=87%.
   The probability of detection=98.5%.
3. *5 males and 5 females emerging/acre:*
   Theoretical control=74%.
   The probability of detection=99.9%.
4. *10 males and 10 females emerging/acre:*
   Theoretical control=about 67%.
   The probability of detection=99.999%.

(1) The institution of a well-organized and unified boll weevil management program designed to reduce populations each year to a level that will not require in-season applications of insecticides. This is necessary to make possible effective management of the bollworm, budworm, and other secondary pests by integrated systems that rely primarily on natural biological control. (2) The institution of a program designed to eliminate the boll weevil from all areas of the Cotton Belt and maintain elimination of incipient infestations that may result from infiltrations from Mexico or from wild hosts in South Texas.

Based on an analysis of the dynamics of the boll weevil and current methods of suppression, intensive use of insecticides will be required in the fall each year to reduce overwintered populations to a level that will assure no need for in-season insecticide applications. However, based on simulated suppression models, the prospects are excellent that such reduced populations will be amenable to further suppression or elimination by employing the boll weevil pheromones and sterile males, two techniques that are completely selective in action on the target pest. The principles and mechanisms of suppression inherent in these new techniques when employed alone and when employed as components in integrated systems add new dimensions to boll weevil suppression strategies. The use of in-field pheromone traps as a method of suppression and as a highly sensitive method of detecting low-level populations shows unusual promise, based on theoretical suppression models.

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THE ELIMINATION CONCEPT AND ITS ALTERNATIVES

By L. D. Newsom[1]

Misunderstandings often arise because terms are not clearly defined. In order that I not be misunderstood, there are two words in the title of my discussion that require definition. The first, "elimination," comes from "eliminate," which is defined in most dictionaries as "to remove and get rid of." One of the synonyms listed for "eliminate" is "eradicate." It is obvious that this conference was designed to set the stage for the implementation of a program having as its objective the eradication of the boll weevil from the United States, and I therefore suggest that we substitute for "elimination" the more honest and forthright term "eradication." The second word, "concept," is defined as "a thought, an opinion, or an idea."

Eradication is the most preferable of all tactics for managing populations of the boll weevil, or any other pest species, because it is permament, and when the technology for eradicating any pest species is proved to be available at acceptable costs, economically and environmentally, I will be one of the strongest proponents of the tactic. Until that time, however, I shall continue to view efforts to control the species by eradication as a serious handicap to its control by a strategy based on the sound and proved practices of applied ecology; that is, a strategy that has come to be called pest management.

I am well aware that many persons are as firmly convinced that the technology is now available for accomplishing eradication of the boll weevil as I am that it is not. I have a number of reasons for being convinced that the technology is not available for eradicating the boll weevil from the United States, the foremost being that I have great confidence in the competence of the two technical committees which evaluated the results of the Pilot Boll Weevil Eradication Experiment (PBWEE). Both committees, working independently, apparently arrived at the same conclusion.

The Entomological Society of America Review Committee concluded that "eradication was not accomplished in the core area." The Committee was divided as to whether or not technical feasibility of eradication of boll weevil populations had been demonstrated, *but unanimously expressed reservations concerning any massive eradication undertaking without further research to refine suppressive techniques.* They were cognizant of the very complex operational difficulties that must be overcome if and when a more extensive boll weevil eradication is undertaken. The Committee emphasized the need for improvements in mass production procedures, sterilization procedures, and surveillance techniques.

The Technical Guidance Committee for the PBWEE, in a very carefully worded statement assessing results of the eradication experiment, did not claim that eradication of the boll weevil from the United States was technically and operationally feasible. Their conclusion instead was ". . . that it is technically and operationally feasible to eliminate the boll weevil *as an economic pest* in the United States . . ." (italics mine).

I don't know what "eliminate as an economic pest" means, and I hope that some member of that Committee will yet define the term. I know one thing it means, however, and that is that the committee was unwilling to state that it is technically and operationally feasible to eradicate the boll weevil from the United States.

Thus, neither committee concluded that eradication was achieved in the PBWEE. However, the wording of both reports suggests that there was sharply divided opinion within each committee. Apparently the division of opinion was so extreme in one committee that it chose not to deal with the subject of eradication at all. In-

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stead, its conclusions dealt with something that was not originally an objective of the experiment; namely, the technological and operational feasibility of eliminating the boll weevil as an economic pest in the United States.

Developing a "National Program To Eliminate the Boll Weevil From the United States" is certainly the most ambitious plan of its sort yet conceived. It deserves a firmer foundation than the results of an experiment that are so highly equivocal.

May I suggest that the conclusions of the two groups of eminent scientists who so carefully assessed the results of the PBWEE be given top priority by the officials whose responsibility it is to decide whether or not to recommend implementation of the proposed plan for eradicating the boll weevil from the United States.

Both committee reports recognized problems of major concern to the success of the proposed plan as being those involved in mass production, sterilization, and surveillance procedures and techniques. Techniques for rearing the huge numbers of boll weevils required for sterilization and release in such a program have not been sufficiently perfected. Serious problems in rearing were encountered in the PBWEE, and quotas were not produced as scheduled. This occurred in a situation where the most capable personnel available were operating the rearing facility. It is unreasonable to expect less trouble when the rearing operation is expanded to the extent required. The problems encountered in expanding mass-rearing operations for the pink bollworm in Arizona are illustrative of what may be expected with the boll weevil.

Surveillance techniques are still woefully inadequate, as demonstrated by failure to find one field in the core area until 1972. This occurred during a time when growers were required to report plantings. They will be less likely to report plantings under the new farm program in which one is free to plant as much cotton as he pleases without being required to report any of it. Clearly, it will be most difficult, if not impossible, to get full cooperation of growers anywhere. The problem of getting growers to properly treat acreage where the boll weevil is not an economic pest is virtually insurmountable, and such areas make up at least 30% of the total. The only possible solution to the problem appears to be the development of a more effective and dependable surveillance technique than is now present.

The problem of wild host plants creates an equally critical need for the development of a more effective surveillance technique. The Technical Subcommittee that developed the proposal in assessing the wild host problem states, "It would seem that only *Hibiscus syriacus, Thespesia populnea, Cienfugosia sulphurea* would pose *much of a problem. . .*" (italics mine) However, it does not require "much of a problem" to wreck an "eradication" program. If a cottonfield can be missed for more than a year in an area monitored so intensively as was the core area in the pilot experiment, how much more difficult will it be to locate and delimit "all colonies" of *Cienfugosia drummondii* in the Coastal Plain of Texas and in South Texas? How important as alternate hosts of the boll weevil are *Thespesia populnea* and *Hibiscus syriacus*? Do we know that the boll weevil does not occur on *Gossypium* spp., *Cienfugosia heterophylla*, and *T. populnea* in south Florida?

The question of the width of the buffer zone required to cope with the flight range of the boll weevil deserves the most thorough consideration. Is 50 mi wide enough, or will it turn out to be much greater? The experience with the screwworm suggests that it may need to be substantially greater. I believe that 35 mi was considered to be an adequate buffer zone when the screwworm eradication program was initiated. That was later increased to very substantially more than 100 mi, I believe.

Another point that deserves careful consideration in establishing the width of buffer zones is Glick's report that he collected boll weevils at an altitude of 2,000 ft. Recent developments in biometeorology and insect flight suggest that a population of airborne boll weevils at a height of 2,000 ft may be displaced by wind for very great distances indeed.

The problems discussed above are important, but the possibility of the boll weevil's developing resistance to the organophosphorous insecticides is by far the most critical problem of all. The National Cotton Council's Technical Subcommittee was well aware of the gravity of the possibility of the boll weevil's becoming resistant to the organophosphorus (O-P) insecticides. It expressed its concern as follows: "If the boll weevil should become resistant to the organophosphorus insecticides, cotton production would suffer and severe economic consequences would follow." If there is any statement upon which we all can agree, this is it. However, when we consider the most likely way that resistance to the O-P insecticides in the boll weevil might come about, our differences begin to appear.

The National Cotton Council's Technical Sub-Committee apparently concludes that the alternatives to the eradication program are the procedures most likely to result in the boll weevil becoming resistant to the O-P insecticides. I believe that the reverse is true. If I were given the responsibility to develop resistance to the O-P insecticides in the boll weevil, I would use insecticides exactly as is recommended in Phase I of the proposed elimination programs; namely, I would have "mandatory in-season control program on all cottonfields by growers." Such a procedure would subject the boll weevil to the greatest amount of pressure ever exerted by O-P insecticides. If the species possesses in its gene pool the mechanisms necessary for development of resistance to the O-P insecticides, the intense selective pressure of the procedure recommended in phase I of the proposed plan would be likely to fix them in the surviving population.

It is not the duration of time to which a population is exposed to a toxicant that is most important in the selection of resistant individuals, but the intensity of the selection pressure applied, and the percentage of the total population exposed. Mandatory treatment of all acreage, at the level emphasized in the proposed plan, is described as follows: "It cannot be overemphasized that the degree of thoroughness and precision necessary in the application of insecticides to reduce populations to levels that are amenable to elimination by suppressive measures in phases 3 and 4 . . . are far more demanding than for merely managing boll weevils for purposes of minimizing losses." Unquestionably, such a procedure would result in exposure of a higher percentage of the total boll weevil population to heavier selective pressure from the O-P insecticides than any procedure that has ever been practiced or proposed.

The diapause treatments currently being practiced as one of the most effective tactics in the strategy of managing boll weevil populations impose a dangerously high hazard of selecting for resistance to the O-P insecticides. However, the proposed elimination program would subject the total population to substantially more selective pressure than ever before applied, even in the diapause treatments, and poses a risk too great to accept. Are you willing to take a chance that the eradication plan may fail and leave us with a population of O-P resistant boll weevils? I am not, nor should anyone else be until something is available that is far more substantial than a plan described as a "concept" by its proponents. You will recall that "concept" was defined earlier as "a thought, opinion, or idea." Thus, a plan for boll weevil control based on a "concept" is a poor alternative to a strategy of pest management that has proved to be effective at acceptable economic and environmental costs over a period of many years.

There is one other probable adverse effect of implementing the eradication plan that is adequate cause for grave concern. What would be the effects of a mandatory program of intensive in-season insecticide treatment on the tobacco budworm problem in the Rio Grande Valley and other areas of Texas? On the tobacco budworm and bandedwing whitefly in the Red River Valley of Louisiana? Catastrophic, probably!

There is another very important reason why I am opposed to the implementation of a "National Program To Eliminate the Boll Weevil From the United States." The history of "eradication" efforts directed at living organisms has been a long chronicle of huge and costly failures interspersed with very few notable successes. Among the latter have been the eradication of the Texas fever tick from the Southern United States, the Mediterranean fruit fly from Florida, several times, and the screwworm from the Southeastern United States.

However, the ratio of failure to success has been so great that no attempt should be undertaken to eradicate any pest species that is well adapted and established over a large land mass until the technology required has been proved unequivocably. Even then, the probability that eradication will be achieved ranges from very little to none. The best example to illustrate this point is that of the screwworm. The eradication program for this pest was implemented for the Southwest during 1962. There has been no year since the program was initiated that cases of screwworm infestations have not been recorded in the area. The numbers of cases reported for

Texas alone each year for the period 1962–73 are as follows: 49,484 ('62), 4,916 ('63), 223 ('64), 466 ('65), 1,203 ('66), 835 ('67), 9,268 ('68), 161 ('69), 92 ('70), 444 ('71), 90,980 ('72), and 8,913 ('73).

This is the record of what has happened with a pest that is poorly adapted and unable successfully to overwinter in a vast majority of the affected area. It is the record of what has happened in a program in which the technology had been proved effective in experiments on an island and on a large peninsula of mainland. It is the record of a program based on a technology that could have no adverse effects, even if it failed to accomplish its objectives, as it has.

By contrast, the program being proposed has not been proved effective on any scale of operation. The contention that the PBWEE demonstrated the technical feasibility of eradicating boll weevil populations has even less validity than the following announcement concerning eradication of the screwworm that appeared in the July 1966 issue of the U.S. Department of Agriculture's magazine Agricultural Research:

"The screwworm has been eradicated from the United States.

"This marks the first time that a wide-ranging insect species has been eliminated from this country using sexual sterility as the eradication tool. The screwworm literally was caused to destroy itself . . . .

"Eradication came after 5 years of intensive State–Federal effort in two separate campaigns: In the Southeastern United States during 1957–59, and in the Southwest from 1962 to the present. About $32 million went for eradication and protection costs—about one-third the cost of damage that screwworms can cause in one bad year."

I am waiting for the sequel to that story. Thus far, it has not appeared.

If the PBWEE had proved that there was or was not the technology available to accomplish the eradication of the boll weevil from the United States, there would have been no need to hold this conference. Instead, neither of two separate committees that assessed the results of the PBWEE could conclude that the technology required for eradication is available. Therefore, the implementation of a program having as its objective the eradication of the boll weevil from the United States, or even from a major portion of the area now affected, is an idea that should be abandoned.

In my opinion there is only one alternative to the concept of elimination, and that is a program of pest management soundly based on applied ecology. Statements contending that we can no longer afford to live with the problems caused by the boll weevil are only partly correct. There are many areas in the aggregate making up a high percentage of the total infested acreage, in which the boll weevil is being controlled effectively and at completely acceptable economic and environmental costs. Technology has recently developed to the point that allows an effective pest-management system to be implemented for all of the infested areas. The effectiveness of the system has been proved in large-scale experiments in several localities. It provides a degree of control for the boll weevil never previously attained, and at economic and environmental costs tolerable to the grower and all other segments of society.

Much of this new technology was tested and proved to be effective in the PBWEE. This experiment was a magnificent demonstration of what can be accomplished in a short time by a well-coordinated, cooperative reseach effort involving several agencies of both State and Federal Government. Results show unequivocally that all of the components required for initiation of a pest management system to control the boll weevil at a level completely tolerable to society are available now. Such a system consists of the following components: (1) Diapause treatments using O-P insecticides, defoliation and desiccation followed by stalk destruction in areas where harvest can be completed before killing frosts occur. (2) Trap crops of early planted cotton (supplemented by use of grandlure when it becomes commercially available) in which overwintered boll weevils are concentrated and destroyed by appropriate insecticide treatment before they can reproduce. (3) In-season trapping with grandlure as soon as it becomes available. (4) Conservation of populations of native natural enemies by delaying as long as possible, or eliminating entirely, in-season applications of insecticides, and use of the most narrowly selective insecticides available when, and if, control of the boll weevil or other pests becomes necessary. (5) Use of early maturing varieties in areas where agronomically acceptable, adapted areas where agronomically acceptable, adapted varieties are available.

The effectiveness of a pest management system based on these components has been proved and demonstrated in large scale experiments. Other components that will improve the system's effectiveness can be added to it as they become available from additional research, e.g., release of sterilized boll weevils and use of resistant varieties.

Such a system would have the added advantage of relaxing the selective pressure of insecticides on resistant populations of tobacco budworm and the bandedwing whitefly. It should prevent further development of resistance in these pests. Moreover, it is possible that relaxation of insecticide pressure on these two species would allow reasonably rapid reversion toward susceptibility to occur in resistant populations.

The system would have only one element that would be cause for concern, namely, the possibility that enough selective pressure could be applied in diapause treatments to select populations resistant to the O-P insecticides. However, it would not be as likely to select for resistance to the O-P's as the eradication program that calls for the mandatory in-season treatment of all cotton acreage in phase I of the proposed scheme. Also, it is an encouraging fact that no appreciable levels of O-P resistance in the boll weevil have developed during almost two decades of extensive and intensive in-season applications of these chemicals.

Is it not a more reasonable approach to boll weevil control to adopt this proved method of pest management than to embark upon a concept that has been tested, and found to be a failure, in only one experiment? Funds saved could be devoted more appropriately to finding solutions to the problems that caused the Pilot Boll Weevil Eradication Experiment to be a failure.

A PLAN FOR BOLL WEEVIL ELIMINATION IN THE COTTON BELT

By J. R. Brazzel[1]

The results of the Pilot Boll Weevil Eradication Experiment (PBWEE) have been reported in detail. The Technical Advisory Committee for the experiment evaluated the results and concluded that we had the necessary technology and operational capability for elimination of the boll weevil as an economic pest from the United States by methods which were ecologically acceptable.

Following this evaluation, the Technical Subcommittee for Development of an Overall Plan for Boll Weevil Elimination from the United States, which was appointed by Robert Coker, chairman of the cotton industry committee, proceeded to develop a general plan. In recognition of the fact that such an undertaking would require a cooperative effort of many agencies and groups, the planning committee members represented research, extension, regulatory, and cotton industry interests.

The overall plan for boll weevil elimination was presented to and accepted by the National Cotton Council Committee on December 3–4, 1973. The National Cotton Council subsequently presented the plan to the Secretary of Agriculture on December 12, 1973. At present, the plan is under study in the Department.

The plan covers all aspects of program execution and will be discussed in detail elsewhere. My presentation will cover the operational aspects of the project. It should be emphasized that this is a general plan designed for guidance of the agencies and industry representatives who would have responsibility for implementation if the decision is made to proceed with a national program.

A national program for boll weevil elimination will require a large number of well qualified, highly motivated personnel for success. The pool of experienced personnel who have direct experience in this type activity is almost entirely limited to those who worked on the PBWEE. Further, the PBWEE demonstrated that great attention to detail was required to successfully execute the various suppression measures. Because of these requirements, the need for other resources, and the logistics of such a huge undertaking, it was decided that it would not be possible to execute the program simultaneously over the entire infested area.

The operational plan is therefore based upon execution of the program in increments or zones across the infested area. The zones were established using the following criteria: (1) Similarity of production practices, (2) adequate size to prevent reinfestation over the zone by migrating boll weevils, (3) placement which takes advantage of breaks in the density of cotton plantings across the area, and (4) logistically feasible size. This procedure resulted in division of the area into nine zones as indicated in figure 1.

It was then necessary to decide where to initiate this stepwise scheme for program execution. From technical and operational standpoints, it would be poor strategy to begin the national program in the center of the infested area, as the pilot test site was. Such a beginning would initially require operational efforts on two fronts. The nature of the program is such that it will be necessary to take advantage of good geographical barriers in order to minimize the infiltration of weevils into zones under suppression, or zones where the pest has been eliminated. Once a front is established, it must be kept moving progressively, and at maximum depth with each advance. Available resources and personnel will not per-

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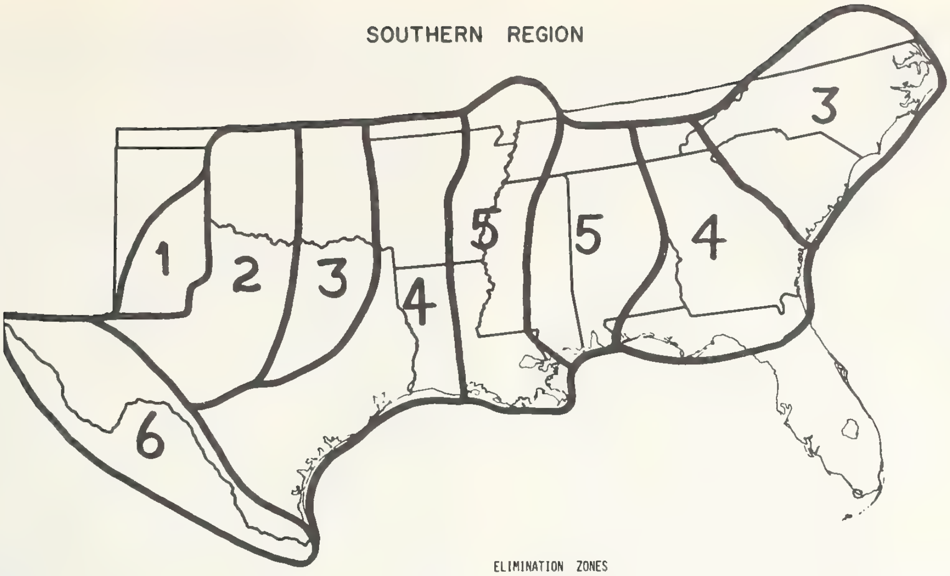

FIGURE 1.—The nine elimination zones for a possible national boll weevil eradication program.

mit an initial active two-front operation of a scope sufficient to assure suppression with a minimum overlap in operations in the various suppression phases.

It would be highly advantageous to initiate the program in an area where the operational group has had experience in large-scale activities. This would be an invaluable aid in achieving the difficult early period shakedown during the time operational procedures must be mastered and a great deal of training must be done.

The following criteria were considered in determining a starting point and a pattern for progression across the infested area: (1) Initiation of the program should be on the periphery of the infested area, and in an area so located as to allow an orderly progression into other zones. (2) It should be located geographically so that natural reinfestation from behind does not occur, and so that chances for reinfestation from the front or flanks, either by natural spread or by movement of equipment or cotton or both will be minimal. Regulatory problems and standards must be considered in the establishment of zones. (3) Initially, it must not result in a two-front program. However, when trained personnel and technological process reach the point that it seems feasible, consideration should be given to a program on a second front. (4) It must be in an area where legislative authority exists for requiring 100% participation of growers. (5) The program should start in an area in which obstacles to effective program operations such as small fields, high trees, and other obstacles around fields; abundant hibernation areas; and frequent rains are less demanding, in order to allow time for development of well trained, experienced, and efficient teams before the extremely difficult areas, such as the Southeast, are encountered.

A review of these criteria and an evaluation of the nature of the boll weevil problem in the various zones indicate that program operations should start at either the eastern or western periphery of the area. This presents two alternatives: (1) Begin in northwest Texas and proceed to the east. (2) Begin in Virginia and the Carolinas and work toward the west. A beginning in Texas will present a situation in which after the third year the boll weevil cleared zones would have to be protected from reinfestation from South Texas and Mexico, since it is not proposed to work zone 6 in South Texas and Mexico until the infestation is cleared from the remainder of the United States. However, an excellent natural barrier zone, approximately 100 mi in depth could be established north of the Rio Grande in South Texas where little or no cotton is planted. With the necessary quarantine and surveillance measures to prevent reinfestation from South Texas and Mexico, it is felt that this would be an effective barrier to natural spread. Such measures will be required throughout the Cotton Belt as the areas are cleared of the pest.

Starting the program in northwest Texas has many advantages. It is considered to be one of the easiest areas to work operationally. Beginning in this area will allow time for shakedown of the operational team and for necessary training while actually making progress in the program. We already have 10 years experience in boll weevil suppression in the area in a program designed to prevent further westward spread of this pest. Program operations in the area would consist essentially of intensification of the on-going program and enlargement of the program area. In fact, most of the suppression methods to be used in an elimination program were further developed and field-tested in this area during the last 10 years. As a result of the on-going program, farmers in the area are well advised on program objectives and actively support the effort. It is appreciated, however, that the elimination program will be much more demanding in terms of thoroughness and attention to detail in execution than has been required for the containment program.

The alternative of starting in Virginia and the Carolinas has the advantage of eliminating the fear of reinfestation from the rear or flank. It also is an area in which positive proof of elimination could be demonstrated rather quickly. Much of the cotton in the area along the northeast periphery of cotton production is scattered, and acreage in the region is much lower than in Texas. It would be possible to lay out a zone of which a sizeable portion would have 100 or more miles isolation from established infestations.

However, this area and the remainder of the Southeast is considered to be the most difficult to handle of the entire belt. When operations reach the Southeast, it will be necessary to have well trained, highly efficient, and disciplined teams to assure success. This area will be as difficult as the pilot test location for program execution. If the program started in this area, it would probably require 2 or 3 years to mobilize resources and develop the necessary expertise to make substantial headway.

For the reasons given above, the committee recommended that a national program should start in the High and Rolling Plains of Texas in zone 1. The progression of the program across the infested area starting from zone 1 offers several alternatives. The most logical ones are: (1) Proceed in an easterly direction by zone for 2 years, during which time additional personnel would be trained to open a second front on the eastern edge of the belt in the third year. Then the two teams would meet in the Midsouth in the fifth year to complete the belt, except for Texas (see fig. 1). (2) Proceed in an easterly direction across the belt, enlarging the area of operations each year as efficiency increases, which would allow completion of the belt during a shorter time period. (3) Proceed in an easterly direction, adding a new zone each year through zone 3 in the east, and then return to zone 6 in the ninth year.

The advantages and disadvantages of these alternatives are seen as follows:

(1) Proceed eastward for 2 years, then open a second front on the east, the two teams working to the center in 5 years.—This scheme would be dependent upon increasing efficiency of program operations and adequate trained manpower. It would have the advantage of offering early relief of the boll weevil problem in the southeastern States, an area in which the economic benefits of the program will be great. It will also shorten the total life of the program, which is true of alternative number two also, but like alternative two, it will require more resources per year than alternative number three. The committee recommends alternative number one as the most desirable approach if the requirements for execution can be met. This recommendation is based upon the desirability of furnishing relief in an area where losses from the insect are especially high. It will also serve to enhance grower interest and support across the belt by shortening the longer wait for relief inherent in the other alternatives.

(2) Proceed eastward across the belt, but enlarge the area of operation each year to shorten the time required for program completion.—This alternative also would be dependent upon increasing efficiency of program operations and adequate trained personnel. The shorter time span for completion would afford quicker relief of the boll weevil problem and lessen the hazard of reinfestation from within the operations area. It would lower costs to some extent by reducing the amount of treatment necessary at the interface of adjacent zones of operations. This approach would require yearly increases in labor, equipment, and services because of the greater scope of operations. It could also create prob-

lems as a result of the size of geographical areas and the probability that natural breaks in cotton plantings could not be utilized in setting up zones of operation.

(3) Proceed eastward by zone across the belt.—This would require the longest time period for completion (11 years), which would not only result in an extended delay before relief of the boll weevil problem could be realized in the Southeastern States, but would also increase the peril of reinfestation from populations within the elimination area. It would have an advantage of requiring fewer personnel, less equipment, and fewer services each year, since the program would be spread out over a longer time period.

In any of the above schemes, a holding zone involving regulatory and quarantine measures would be created along the northern part of the Rio Grande Valley cotton zone, so as to minimize chances for reinfestation as the program proceeds into other areas.

Although recommendations have already been made that effective boll weevil management programs be organized and expanded in various zones prior to the initiation of the elimination program, it is especially important that such management programs be implemented in the Rio Grande Valley zone concurrent with the start of the elimination program in zone 1. The suppression of boll weevils through a well supervised management program, plus the enforcement of existing regulations relating to cotton cultural practices in the Lower Rio Grande Valley, should not only provide a high degree of suppression for the growers' benefit, but would minimize the chances of weevil spread across the natural noncotton border into zones where boll weevils have already been eliminated.

The plan of action in each zone will cover a period of 3 years, with followup in subsequent years of thorough survey and detection activities by local agencies. Through informational and educational efforts by extension and other appropriate agencies, an attempt should be made to get the growers in each zone to organize and implement a boll weevil management program prior to initiation of program operations. Such a program would be designed to maintain boll weevil populations below the economic threshold level by a minimum use of insecticides during the growing season. The management program, initiated ahead of the elimination program, would be carried out for the purpose of efficient cotton production, but at the same time would make a major contribution to success in the elimination of the pest at minimum cost.

Operational activities by year in a zone include (see fig. 2):

First year.—(1) Move the necessary personnel into the area and organize into work zones, areas, and units during the spring. (2) Set up traps in the work areas to start the survey pro-

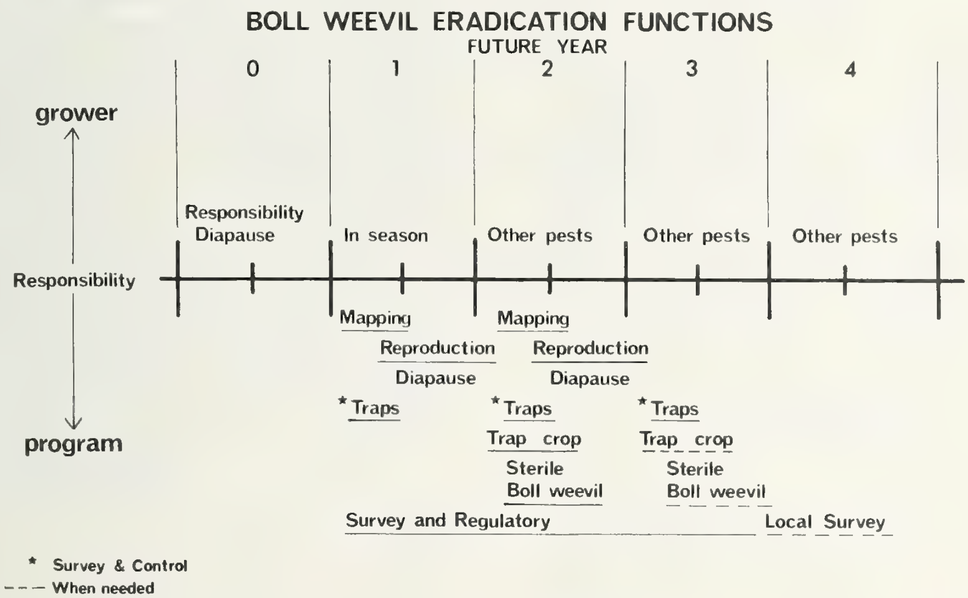

FIGURE 2.—Operational activities by year in an eradication zone.

gram by the time spring emergence begins. Traps will be used throughout the year to monitor populations and to identify localized areas where the boll weevil problem is likely to be most severe. (3) Begin field surveys and mapping as soon as cotton emerges, and continue surveys throughout the season. (4) After cotton has emerged, aerially map the area to locate all cottonfields. (5) Furnish survey data to the Extension Service to insure farmer treatment of any boll weevil infestation when warranted (phase 1). (6) Treat, in-season, any infestation of concern, if the grower does not treat at the request of the program management. (7) Initiate and execute phase 2, starting with the reproduction-diapause spray schedule at the appropriate time. (8) Use the necessary preharvest chemicals (cotton growth regulators) to insure an early and efficient harvest. (9) Take the necessary action to destroy stalks after harvest, when appropriate. (10) Take the necessary action to prevent regrowth of cotton after harvest. (11) Make an evaluation report of the first year of operations.

Second year.—(1) Continue to operate traps throughout the year to monitor the population. (2) Establish trap crops with pheromone stations at the appropriate time in the spring (phase 3), and operate until grower cotton eliminates their effectiveness (at least until August 15). (3) Remap the cotton in the area as soon as it comes up. (4) Aerially map the area as soon as the cotton comes up. (5) Intensify field surveys throughout the season to monitor populations and evaluate the program. (6) Begin sterile-insect drops prior to fruiting of cotton, and continue throughout the season as long as boll weevil reproduction can occur. (7) Spot-treat with chemicals any incipient infestation found in surveys that are not contained by sterile males. (8) Apply a presquare treatment to any area in which surveys reveal a threatening boll weevil population that will be beyond the scope of management by sterile-male releases. (9) Execute a reproduction-diapause program in areas of suspected incipient infestations with the appropriate cultural practices. (10) Make an evaluation report of the 2 years of operations.

Third year.—(1) Continue to operate traps at a lesser degree of intensity throughout the year to monitor potential boll weevil populations. (2) Put in trap plots in any area where the experience of the previous year indicated a potential overwintering population. (3) Aerially map the area when the cotton emerges. (4) Do a selected visual field survey over the area. (5) Drop sterile insects over an area within 25 mi adjacent to the infested zone at the front of the program. (6) Spot-treat with chemicals any areas of suspected incipient populations that may not be adequately suppressed by sterile males.

By this procedure, the operational team will complete its work in each zone over a 3-year period. The insect survey and detection activity, which would be a followup in the fourth and subsequent years, would be handled by appropriate State and Federal agencies. As each new zone is picked up each year, the 3-year cycle of activities would begin. Thus, by the third year, operations would be underway in three zones, each with the type of activities described herein for each year. By the fourth year of the program, operations could cease in the zone where the program was initiated, and, even if no boll weevils appeared to be present, monitoring would continue so as to locate any incipient infestation that remains or which may result from reintroduction.

Once again, this is a general plan. If a national program is undertaken it will be necessary to develop a much more detailed plan of action, along with an environmental impact statement. It is estimated that completion of such a program would require 6 to 10 years and would cost $655 million, based upon 1972 cotton acreage. This cost estimate includes a 20% contingency fund.

Finally, there are certain conditions which are essential to the success of such a huge and difficult undertaking: (1) There must be overwhelming support of the program by growers, the cotton industry, and the agencies responsible for program execution. (2) There must be 100% grower participation. (3) We must have the legislative authority to carry out the regulatory requirements and the willingness to exercise that authority. (4) The growers must be willing to contribute up to 50% of the cost of the program. (5) We must further refine our technology and improve efficiency in execution. (6) We must develop well trained, highly motivated personnel capable of giving the attention to detail necessary for successful execution of the program elements.

REGULATORY ASPECTS OF BOLL WEEVIL ERADICATION IN THE COTTON BELT

By H. L. Bruer[1]

The technical committee for determining an overall plan for a program to eliminate the cotton boll weevil from the United States divided its work among subcommittees, one of which was that concerned primarily with regulatory aspects. The committee discussed these requirements as fully as possible in the overall plan, which was published on December 4, 1973. For a more comprehensive discussion of these needs, this overall report should be consulted.

Jim Brown, the committee chairman, listed the regulatory requirements as the six C's: clearance, course of action, cooperation, coordination, cost allocation, and compliance. There should be no difficulty in interpreting these terms. "Clearance" simply entails authority for the effort to eliminate the boll weevil. "Course of action" has to do with the technical plans for such action, including the establishment and administration of elimination zones. "Cooperation" in this context takes on a rather special meaning in that it requires 100% participation. E. F. Knipling phrases it as "full cooperation of all cotton producers." "Coordination" entails such steps in an overall program as a reporting system for cotton acreage, destruction of small isolated plantings, and other items of a similar nature. "Cost allocations" is fully covered in Section 611 of Public Law 93–86 enacted on August 10, 1973. This law will be discussed in more detail later. "Compliance" in the present context comprises such terms as right of entry, quarantines, or other regulations governing movements through eradication zones, disposition of noncommercial cotton, and similiar problems.

Let us consider a little further Public Law 93–86 which constitutes Appendix H in the report of this full committee. I shall not attempt to quote it in its entirety, but will quote certain pertinent passages which are of particular significance. In the first place this law states that "the Secretary," meaning the Secretary of Agriculture of the United States, "is authorized and directed to carry out programs to destroy and eliminate cotton boll weevils." The law further states "the Secretary shall carry out the eradication programs authorized by this subsection through the Commodity Credit Corporation." I am not exactly sure of the meaning of this passage, but I would presume that it is the intention of Congress that necessary funds be provided by or channeled through the Commodity Credit Corporation. To read further from this law, "producers and landowners in an eradication zone, established by the Secretary, who are receiving benefits from any program administered by the United States Department of Agriculture, shall, as a condition of receiving or continuing any such benefits, participate in and cooperate with the eradication project, as specified in regulations of the Secretary. The Secretary may issue such regulations as he deems necessary to enforce the provisions of this subsection with respect to achieving the compliance of producers and landowners who are not receiving benefits from any program administered by the United States Department of Agriculture. Any person who knowingly violates any such regulation promulgated by the Secretary under this subsection may be assessed a civil penalty of not to exceed $5,000 for each offense.

"The cost of the program in each eradication zone shall be determined, and cotton producers in the zone shall be required to pay up to one-half thereof. . . ."

The act further provides "each producer's pro

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rata share shall be deducted from his cotton payment under this Act or otherwise collected, as provided in regulations of the Secretary." Since there are no payments presently made under this Act, it is obvious that the producer's shares will have to be collected in some other manner.

From the above, it would seem that any authorization necessary for the implementation of a program for the elimination of the boll weevil is vested in the Secretary of Agriculture. This is quite a remarkable law in that it represents a complete departure from laws that have been followed for years in control and eradication efforts in this country. There has always been cooperation between the Federal Government and the affected States, and much of the authority for necessary mandatory provisions has been vested in the States. For example, the Federal authorities heretofore have never had the right of entry on private property. This has always been a function of the State authority. Whether or not the Secretary of Agriculture contemplates this kind of change in the traditional relationship between the Federal Department of Agriculture and the States, I am not in a position to say. I have had some discussion on this point with agencies of the U.S. Department of Agriculture. Those who would under normal circumstances be actively engaged in an eradication effort of this kind have assured me that they anticipate and expect the cooperation of the States along lines similar to those which have been followed in past eradication programs of this kind. In anticipation of this, the committee circularized the States infested with boll weevil to determine whether or not all of these States had the authority necessary for the operation of such a program. We found that while most of the States had most of the authority that would be required, all of the States lacked authority for one or more elements that the committee regarded as essential, and that therefore some revision of State statutes seems to be indicated.

As one who has devoted 40 years to control and eradication programs similar to the one contemplated, I have done investigations in support of such programs, I have been actively engaged in the control work, and, for the past 20 years, have been in a position where it was necessary for me to apply whatever mandatory steps were necessary in connection with such programs. In those 40 years, I believe that I have learned something of such work, and while I cannot give infallible advice as to how to succeed in this effort, I can with entire certainty define the way to fail in it, and that is to make the effort for boll weevil eradication without having made sure of the overwhelming support of all the affected cotton producers. In other words, voluntary compliance with the needs of the program is essential. Otherwise the program fails. I believe that technologically the problems have been or can be solved. The most questionable problems are "people problems," which is to say, operational problems. It does not matter how much authority is vested in the Secretary of Agriculture or in the various State control officials. There is no way to prevent citizens of the United States from recourse to the courts, and if even a small minority of such citizens decide to take this recourse in opposition to the program, the program will be lost in that particular area for at least 1 year, most likely 2. It does not matter that the program may eventually win the case. The delay of the law will negate the eradication effort for at least the period of time indicated. It might be argued that the only opposition to the proposed program would come from small, poorly informed growers who would not be financially in position to offer such legal challenges. It should be recalled, however, that we are now in the era of class litigation, and that there are agencies who are simply standing about waiting for some ill-financed group to initiate such an action while they provide the necessary financial muscle and legal talent. It is, therefore, essential that the cotton growers' enthusiastic cooperation be enlisted to the greatest extent possible.

This brings us to some hard but necessary decisions which must be made—if not immediately, then in the very near future: (1) How is the cooperation of the growers to be enlisted and maintained? (2) How are the growers' opinions to be measured? (3) Are the mandatory aspects of this program to be completely Federal or Federal-State cooperative? These decisions must be made.

EXTENSION AND INFORMATION ROLES IN BOLL WEEVIL ELIMINATION

By J. E. Jernigan[1]

Since the primary function of the Extension Service is education, we would focus our attention on getting information to all people concerned, providing leadership in organizing producer groups for effective conduct of the program, and encouraging voluntary participation by farmers.

There is no doubt about the importance of an effective educational program in undertaking a project of this nature and magnitude. Gaining enthusiastic farmer cooperation and participation, rather than forcing compliance by rules and regulations, will make the job easier and more effective. If everyone in an area fully understands the objectives of eliminating the boll weevil, the economic impact of this pest, the amount of insecticides used for its control, and the operational procedures for the program, it will help keep false rumors to a minimum and reduce problems associated with this effort.

The elimination program is divided into two separate phases, each of which will require educational efforts aimed at maintaining good communication among all parties concerned. The first part of the program will be aimed at getting growers to follow a good in-season boll weevil control program, followed by an areawide diapause effort in the fall. This will be a voluntary program on the growers part, but highly important in reducing the weevil population before beginning the formal elimination program the following spring.

The second phase of the program will begin with activities conducted and supervised by operational people responsible for carrying out the formal elimination program. Extension will be largely responsible for the first phase of the program, since it consists primarily of intensifying and carrying out current recommendations for boll weevil control. During the second phase of the elimination program, Extension will be responsible for conducting the educational phase of the program as well as serving as a coordinator between agencies, growers, and the public.

From an Extension point of view, based on experience gained in the Pilot Boll Weevil Eradication Experiment, there are three primary audiences concerned with the elimination effort. These are (1) county agents and other professional agricultural workers in the area, (2) cotton producers and other farmers, and (3) the general public. Each group is vitally important to the success of the program, and Extension will provide the educational leadership to see that each group is properly informed.

County agents will need to be trained in order that they may serve as dynamic leaders in carrying out the total program. They will have to be given complete information about the program, including the technology and operational procedures involved. They will also take the lead in organizing growers to carry out the first phase of the elimination program, which consists of in-season boll weevil control and diapause control. County agents will also prepare communications for the media, conduct farmer meetings, write letters to growers, and follow up problems with personal contacts. Cotton producers and other farmers will need information about the objectives of the program and an outline of program activities. This will help them understand the division of responsibility for all participants and the timing of the various practices to be carried out. Participants will be given assistance in setting up the necessary organizations for conducting the total elimination program.

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To provide information to the grower, Extension will prepare circular letters, news articles, radio and television scripts, slide sets, and films about the program. County agents and Extension specialists will organize and conduct community meetings to inform growers about all activities of the program. Individual visits will also be made with farmers, particularly in problem areas, to make sure there is no misunderstanding about program activities and to promote mutual cooperation.

The general public will also be given appropriate information so that they will understand the objectives of the program, the impact it will make upon the environment, and the need for their cooperation in such matters as protecting traps and eliminating cotton plants from flower beds. Extension will aim its educational program at these people through the mass media and by making talks at civic clubs and sportsman associations.

Progress reports on the program will be made at appropriate times through all channels available to keep all audiences informed.

To maintain accurate distribution of information about the project, it is suggested that an educational committee representing all agencies involved be formed to check articles for use by the media. The committee would need to designate someone to clear all material being prepared for this purpose. The information committee would also be responsible for preparation of slide sets and scripts, television spots, and other visuals for use in meetings and conferences.

A full-time Extension entomologist designated as a coordinator in each State, and one at the national level, will work closely with personnel from all agencies involved to make sure communications are getting through and being understood. The national coordinator will work closely with professional people in the land-grant universities and U.S. Department of Agriculture to make sure concensus is reached among States and disciplines involved in carrying out recommendations. Many misunderstandings and problems can be avoided through good communications.

Experience gained in the Pilot Boll Weevil Eradication Experiment showed that cooperation among the many agencies needed in carrying out this project is possible and obtainable. Monthly meeting of personnel from each agency proved to be an invaluable source of communication while the project was in operation. Such a plan would, no doubt, serve the best interest of any future elimination project.

Extension administrators in the States involved recognize the role Extension must play in such a project, and they have indicated a genuine interest in cooperating to the extent that resources are available in the first phase of the program in 1974.

To begin the program, a committee of Extension and industry leaders in each State will review the proposal, decide what is needed in their local area, and set the plan in action during the spring of 1974. If funds are made available for the elimination project, Extension would then assume responsibility for conducting its educational role in the second phase of the program to the extent that resources allow.

RESEARCH REQUIREMENTS FOR BOLL WEEVIL ELIMINATION IN THE COTTON BELT

By Waldemar Klassen[1]

The Pilot Boll Weevil Eradication Experiment (PBWEE) demonstrated that we now have the essential tools for detecting and eliminating boll weevil populations. The challenge now is to make marked improvements in these tools in order to increase the reliability of the suppressive system and to reduce the cost of its implementation.

The U.S. Department of Agriculture has not yet taken a position regarding a program for either beltwide boll weevil elimination or population management. Even so, we do not wish to lose research momentum unduly, since—in any event—the information generated will be useful in fighting this key cotton pest. We also know that research always requires ample lead time and scientists with uninterrupted total immersion in the problems to be solved.

I am convinced that through cooperative State-Federal-industry research we can further develop systems for boll weevil elimination which have enhanced reliability and economy in cotton growing. The rate of progress will depend upon how effectively we adjust our mechanisms for setting priorities, for allocating program coordination in specific problem areas to the most appropriate scientists, and for maintaining a sense of unity and esprit de corps. Likewise, research progress will depend on the continued encouragement and resolute support of research administrators, the cotton and chemical industries, growers, and legislative bodies.

While the research of many scientists would be substantially accelerated by modest increases in funds, we recognize that we already have a sturdy cooperative program of nearly 30 scientist man-years. Moreover, some of the best scientists in the Nation are working on the boll weevil, including some of the most capable leaders in the entomological profession. The struggle against the boll weevil has substantially benefitted, moreover, from the vexations of several outstanding devil's advocates. Further, this effort is fostered by as creative and dynamic a group of agricultural research administrators as can be found anywhere. We also continue to receive superb assistance from extension and regulatory agencies.

The favorable outcome of the PBWEE and other concurrent and continuing improvements in technology indicate what this community of agricultural workers can accomplish if greatly challenged and greatly led. During the past 6 months or so, nutritional improvements have been made in the artificial diet, and there have been advances in excluding microbial contaminants from diet of adults. Two laboratory methods for completely and permanently sterilizing both sexes of boll weevils have been developed. If these methods can be scaled up successfully, separation of sexes can probably be avoided. Last season it was discovered that pheromone-baited traps placed within fields will catch newly emerged female weevils before they have an opportunity to mate. Successfully developed, these in-field traps may become tools for simultaneous detection, assessment, and suppression at low population levels. In-field traps plus insecticides may have the potential for strongly suppressing populations at all density levels. If so, these traps could substantially reduce costs and the present reliance on sterile males, as well as facilitate more effective deployment of them. Traps may also minimize the supplemental use of insecticides. Moreover, unlike trap rows, in-field traps do not contribute to the development of insecticide resistance.

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Much of the research that provided the tools for population management or elimination has been qualitative in nature. In order to develop more economical and reliable suppressive systems we will have to greatly increase our quantitative knowledge. So far, our major concern has been to determine whether our tools would strongly suppress. Now we need exact measurements on rates, variability, and limits. What percentage of weevils within a given distance from a trap or trap crop will respond and what percentage will be killed? To what extent does suppression by sterile males deviate from that expected? How does the rate of increase of weevils vary as the population density declines? These and many other questions have been on our minds for years, but now we cannot progress satisfactorily without some quantitative answers, and in conducting quantitative research we would benefit greatly from the increased help of engineers and biomathematicians.

I feel that the organization and the technological content of a system for boll weevil population elimination would not differ significantly from that required for managing populations below economic levels in a manner that neither triggers outbreaks of bollworms and tobacco budworms nor predisposes the cottonfields to them. There are some who doubt that sterile males would have a major role in population management because of the technical problems involved in mass rearing and sterilization. I am confident that these problems can be resolved, however, and furthermore believe that the boll weevil is more amenable to suppression with the sterile-male method than many other species. Unlike the screwworm, pink bollworm, and many other pests, it is the male boll weevil which attracts the females, and it is the wild females which must compete for the sterile males. Thus we need to maintain quality in fewer characteristics of the boll weevil to achieve suppression than we do with most other species. In particular, we can be somewhat less concerned about those genetic changes affecting boll weevil behavior that are induced by artificial rearing than would be the case were we dealing with many other species.

Very useful appraisals of research needs can be found in three public documents: "Statement by the Technical Guidance Committee for the Pilot Boll Weevil Eradication Experiment," August 30, 1973; "Overall Plan for a National Program To Eliminate the Boll Weevil From the United States," A Report of Findings and Recommendations of a Technical Subcommittee Appointed by the National Cotton Council of America, December 4, 1973; and "The Pilot Boll Weevil Eradication Experiment," Report of the Entomological Society of America Review Committee (Ann. Entomol. Soc. Am. 19: 218–221, 1973).

The three documents above prove that we scientists are highly proficient in coming up with questions. In fact, we have identified so many questions that with current levels of funding and manpower the essential research will not be complete for a number of years unless we can agree upon a system of priorities.

In the interest of developing a research gameplan which will allow us to attend to the most critical needs in the shortest possible time, and yet not dampen opportunities for important ancillary achievements, I have fearlessly divided the research needs into three categories. Doubtless some of my colleagues will take exception to my placement of one or more of their projects. I invite such scientists to try to persuade me to change my mind.

In setting priorities for boll weevil research, it seems helpful to divide the reseach objectives into three categories, or arrays. The first is the *critical array* which includes only those research objectives which are absolutely essential to obtain major new improvements in the reliability and economy of the boll weevil suppressive system. The second group of research objectives is the *concurrent array*. Achievement of objectives in the concurrent array seems fairly certain, and although such accomplishments are not absolutely essential, they would be very helpful in further increasing the reliability and economy of the suppressive system. The third group of research objectives is the *supplementary array*. The supplementary array contains high-risk objectives as well as those which may or may not prove to be important or needed. These high-risk objectives could result in substantial improvements, but we dare not rely on their accomplishment at this time.

The *critical array* of objectives—those absolutely essential to achieving increased reliability and economy—includes:

(1) Research and development on mass rearing for the reliable production at minimum cost

of vigorous weevils. We must get away from rearing in petri dishes and from heavy reliance on unskilled temporary labor for manipulation requiring aseptic techniques.

(2) Research and development on the sterilization of weevils by feeding on busulfan chemosterilant, followed by immersion in Largon (Thompson-Hayward 6040), or by vacuum fumigation with hempa, followed by feeding on busulfan. Research at Florence, S.C., and at Baton Rouge, La., has shown on a small scale that these two methods fully sterilize both sexes. Research is needed to determine whether or not these methods can be scaled up. We cannot accept less than 98% sterility of males and 99% sterility of females, nor can we accept significantly reduced pheromone production in sterile males.

(3) Research and development on the use of the boll weevil pheromone for predictable suppression when used in traps and trap rows, and for quantitative detection when used in border and in-field traps. Obviously the accomplishment of this objective will require quantitative season-long studies at several locations across the boll weevil belt. Adjustments in deploying the pheromone are most needed in a number of areas of Texas. Scientists in Texas, with industry support, are already hard at work on this problem.

Since some of these critical needs became apparent during the PBWEE, the Agricultural Research Service allocated $150,000 primarily for research on mass rearing. Work on sterilization has been slightly accelerated through redirection of effort. The Animal and Plant Health Inspection Service has continued its methods-development program on these problems. Furthermore, the cotton industry is providing some funds to accelerate the development of the use of grandlure.

In the *concurrent array,* that is, the list of objectives which are likely to be accomplished by highly competent scientists and which definitely would prove to be helpful, I have placed the following (not in order of priority): (1) Research on pheromone to reduce the cost of synthesis and permit the development of a commercial formulation. (2) Research on trap design to improve capture efficiency, reduce cost, and simplify disposal. (3) Research to advance early maturity and the Frego bract trait into widespread commercial use and to develop advanced breeding lines of new boll weevil resistant wild stocks. Early maturity would be especially helpful in areas such as southeastern Texas which are subject to rainy weather in fall. (4) Research to determine the relative effectiveness of azinphosmethyl and malathion, and to refine formulations and methods of application of these insecticides. (5) Collation and publication of data on the efficiency of "bug-catchers" for sampling boll weevil populations. (6) Research to complete an integrated cotton-plant and boll weevil population model. Such a model would be useful in planning and scheduling operational activities such as rearing, quantitative selection of control strategies, and evaluation of results by comparing simulated suppression to observed suppression. (7) Research toward the establishment of a barrier to boll weevil invasion from Mexico. (8) Research to establish optimal handling, holding, and release procedures. (9) Research to refine quality control procedures for mass rearing and sterilization. (10) Research to quantify the onset and time course of migration, the onset and time course of diapause, and the rates of increase of low level populations at several locations, but particularly in the Eastern States and in southern Texas. (11) Research to quantify the environmental impact of boll weevil suppression measures.

In the *supplementary array,* I have placed the following high-risk or contingency objectives: (1) Research to sterilize weevils with fractionated doses of gamma radiation. Studies at our Fargo, N.Dak., laboratory have shown that weevil mortality is greatly reduced if the sterilizing dose is delivered intermittently in 20 fractions. Further, complete infecundity and destruction of primary spermatogonia in males—which is the basis for permanent male sterility—is induced with only one-half of the radiation dose required to induce 100% sterility in mature sperm. Therefore, there still may be a good chance of inducing sterility with gamma rays only, or by a combination of gamma rays plus a chemosterilant. (2) Research to sterilize weevils rapidly by delivering chemosterilant vapors or solutions through the tracheal system to the gonads with reduced atmospheric pressure. These techniques originated at Fargo and Beltsville. (3) Research and development on hibernal trapping, i.e., using pheromone to lure weevils to hibernation sites where they would be destroyed. (4) Research on replacement insecticides to be used if the boll weevil should develop organophosphorus (O-P) resistance. (5) Research to develop boll weevil strains from various sections of the Cotton Belt for release. We must be certain that assortive mating will not occur between the released insects and native insects. Also, we should take advantage of hybrid vigor if it exists. (6) Research to develop special mutant release strains with traits such as the inability to diapause, the inability to fly, and the inability to use the cotton plant's phytosterols for reproduction. (7) Research to completely select out the genetic capacity to diapause in the release strains. Since nondiapause weevils cannot overwinter, and since the nondiapause trait tends to be inherited as a dominant, the program would be insured from the inadvertent failure of the sterilization procedure by the fact that progeny of released weevils would suffer enhanced winter mortality. (8) Research to develop the pheromone for interrupting communication between sexes. (9) Research to establish the frequencies of genes for O-P resistance in local populations and research to determine if weevil populations may respond to diapause control by advancing the onset of diapause in the summer. Experience with many other species has shown that the development of O-P resistance with few exceptions is initially a slow process in which minor genes are accumulated through selection. However, when these minor genes have been assembled, the frequency of a major gene for resistance can increase with considerable speed and decisiveness. (10) Research to determine the need for isomeric purity of grandisol.

I believe everyone agrees that significant improvements in the reliability and economy of the boll weevil suppressive system require substantial accomplishments in all three research objectives in the critical array. Good business sense dictates that we pursue the objectives in the concurrent array, but the early achievement of these objectives is not a prerequisite for initiation of a management or elimination program, and they can be accomplished during the course of such programs to progressively yield improvements. A number of the high-risk and contingency objectives in the supplementary array may provide breakthroughs that could dramatically improve our capabilities. Therefore, let us support them as best we can.

Even if we could achieve all of the objectives in the three arrays, we still would lack absolute proof that the boll weevil can be eliminated—and eliminated at a cost acceptable to all interests. To satisfy this question we will have to make an effort at elimination for several seasons, and on a scale large enough to eliminate migration as an important factor in making the final judgment.

In its "Overall Plan" the National Cotton Council has suggested that 1.5% of funds made available for a beltwide program should be allocated for research and development. It is vitally important that such an action program should be underpinned by a vigorous research and development program. Such a research and development program would progressively yield improvements and ensure the existence of active boll weevil scientists across the cotton belt for recognizing and heading off trouble, and for solving unforeseen problems.

Although much hard work lies before us, we are rapidly acquiring the essential knowledge and technology needed to deal decisively with the boll weevil at reasonable cost.

REPORT OF INDUSTRY ACTION COMMITTEE

By Robert R. Coker[1]

The National Cotton Council's Beltwide Action Committee on Boll Weevil Elimination was appointed in late 1973, and is made up of cotton industry leaders from throughout the entire Cotton Belt. The committee members are: John Abbott, Harlingen, Tex.; Don Anderson, Lubbock, Tex.; Hugh Arant, Jackson, Miss.; Harry S. Baker, Fresno, Cal.; Harry S. Bell, Columbia, S.C.; Marion Benham, Lovington, N.M.; Robert A. Carson, Lambert, Miss.; Marshall Grant, Garysburg, N.C.; J. Wayne Griggs, Humboldt, Tenn.; Albert McDonald, Huntsville, Ala.; Robert D. Pugh, Portland, Ark.; Dan Pustejovsky, Hillsboro, Tex.; Duke Shackelford, Bonita, La.; P. B. (Bobby) Smith, Winder, Ga.; A. L. Story, Jr., Wolf Island, Mo.; Jess Stratton, Clinton, Okla.; William H. Wyatt, Blytheville, Ark.; and Charles F. Youngker, Buckeye, Ariz.

Advisory members are Dalton Gandy, National Cottonseed Products Association, Memphis; John K. Hosemann, American Farm Bureau Federation, Park Ridge, Ill.; Donald A. Johnson, Plains Cotton Growers, Lubbock, Tex.; George Slater, Cotton Incorporated, Raleigh, N.C.; B. F. Smith, Mississippi Delta Council, Stoneville, Miss.; Robert A. Tucker, Southern Cotton Growers, Dahlonega, Ga.; J. Ritchie Smith, National Cotton Council, Memphis, and Albert Russell, Executive Vice President of the National Cotton Council.

The committee initially met on January 25, 1974, in St. Louis, and in that meeting we shaped our general plans for the job ahead. Our first job is to do all we can to get an early, favorable decision from the Secretary of Agriculture to implement the boll weevil elimination program at the earliest possible time.

Our basic job, of course, assuming a favorable decision by the U.S. Department of Agriculture, is to provide advice and guidance for Cotton Council activities in support of the program at both the Washington level and at the state and local levels. In Washington, we plan to work with the Executive Branch on program specifics, and with the Congress on appropriations. In the States, we will assist in developing State-level committees and procedures to help facilitate the program as it progresses. In some cases, State legislation may be needed, and we expect to provide assistance in such circumstances. In short, we want to do everything we can to help get the elimination job done as quickly as possible.

The following resolution was adopted at the Council's annual meeting in St. Louis late last month. Under the heading of "Boll Weevil Elimination," the resolution commits the Council to:

> Vigorously support a national program to eliminate the boll weevil from the United States as specified in Section 611 of the Agriculture and Consumer Protection Act of 1973 and urge:
>
> a. That the program be started no later than 1975;
>
> b. That producers in the boll weevil belt cooperate fully in the program;
>
> c. That the Council lend its full support and cooperation to the USDA in planning and carrying out the program; and
>
> d. That Extension Services, Federal-State regulatory agencies, and other appropriate agencies assist producers in organizing and carrying out expanded diapause control and other weevil management procedures, starting in 1974 and continuing until the elimination program commences in their areas.

Several of us met in New Orleans with Extension Service directors to review the elimination plan and to shape general plans for ex-

[1] Chairman, National Cotton Council Beltwide Action Committee on Boll Weevil Elimination, P.O. Box 340, Hartsville, South Carolina 29550.

panding ongoing pest-management programs, starting this year. The national elimination plan stresses the need to carry out diapause and other weevil management procedures in advance of the actual elimination program itself. This vital advanced phase will cut interim weevil losses and create better conditions for elimination when the program starts in a zone. A very practical side benefit, of course, is that a good job in the advanced phase will reduce sharply the cost of the program to both producers and the Commodity Credit Corporation. The Extension directors pledged their full cooperation and assistance in carrying out both phases of the program, and we will move immediately to follow through with them and others in the States.

FINAL DISCUSSION

J. R. PHILLIPS, University of Arkansas: I would like to read a statement prepared by myself and Dan Clower, LSU; Floyd Gilliland, Auburn University; Don Rummel, Texas A&M; Jack Bagent, LSU; Herb Womack, University of Georgia; Dale Bottrell, Texas A&M; and Aubrey Harris, Mississippi State University.

1. It has been stated that both the Entomological Society of America and Technical Guidance Committees have expressed reservations of eradication but this thought is not being communicated adequately to the producer and public. Elimination is being used to mean the same as eradication but the Technical Guidance Committee indicated that something less than eradication was achieved, i.e. ". . . elimination of the boll weevil as an economic species. . . ." This point is of grave concern to a number of scientists who will be responsible for implementing the proposed program. We feel the program, based on present data, has obvious weaknesses especially in the areas of mass rearing and sterile release. It, therefore, seems rather presumptious for us to insinuate that we have the technology to eradicate (eliminate) the boll weevil from the United States.

2. We are concerned about the proposed investment that would be made on an eradication (elimination) research effort that appears premature. For example, nothing has been stated relative to the possibility that the program may not go according to schedule. If it does not, which will most likely be the case, how will the proposed budget be adjusted? In case serious errors in judgment have been made, how much will other areas of much needed research be sacrificed budget-wise to continue the eradication (elimination) program?

3. We feel that if we start prematurely our chances of success will indeed be slim and, with failure, the confidence of the American public in agricultural research will be damaged irreparably.

AUBREY HARRIS, Mississippi State University: I would like to comment further on the possibility of an alternative that we might consider for the immediate future in regard to boll weevil eradication. I interpret the statement of the Technical Guidance Committee to be that elimination of the boll weevil as an economic pest would be something less than eradication, and that would imply that we could anticipate resurgence of the boll weevil following the 3-year plan such as has been proposed, if such a plan were begun immediately with current technology. This does not of course preclude the possibility that advanced technology might eliminate this problem of resurgence in the future. It has been asked how an alternative or an interim program might be implemented. A number of people have given a lot of consideration to an interim or an alternative program prior to a boll weevil eradication effort. I say "alternative" in case the boll weevil eradication effort does not become a reality, but would call it an interim program should it become a reality in the near future.

The kind of program that I have in mind would be one in which growers across the Cotton Belt could organize themselves into pest management districts of some kind. I have seen programs of this type proposed for Texas. There are proposals in Mississippi that follow this line. Growers who wish to implement such a program could impose it on themselves, as it were, by a referendum for the area that is assigned and then implement it according to some guidance laid down by technical committees of some kind. One advantage of this approach over the immediate move into a beltwide eradication program would be that it would not commit the Cotton Belt to an eradication program about which there are still reservations. In other words, the approach would not promise more than could be delivered at this time. A second advantage of such a program would be that it would serve the educational and organizational functions in advance of eradication, or could serve as an ongoing program in the event that an eradication program did not develop. So, I think we have a good alternative, and I propose that the people who are considering the program give thought to such an alternative and such a means of implementing adequate boll weevil management without necessarily committing us at this stage to an all-out eradication program.

DON ANDERSON, cotton producer, Lubbock, Tex.: Over the past 12 years I have become well acquainted with many entomologists and the manner in which they approach research. Around 1963, the weevil began climbing up on the Cap Rock and looking at what was then about 2 million acres of cotton there. At that point a lot of entomologists said that the boll weevil was moving into an environment in which he could not live. But a lot of entomologists did not realize that right over on the back side of the High Plains were about 15,000 or 20,000 acres—maybe even 50,000 acres—of Shin oak that he was living in on the east side, and that if he ever made that jump over to the west side there wasn't any way to handle a couple of million acres with the system we had. So we began to search for some solutions to the problems.

The first meeting was held in Floydada, Tex. We called some entomologists together and asked them: Is there any way that this thing can be stopped? They said nope, no way. But we rolled the problem around, and finally somebody mentioned diapause control, which some men named Brazzel and Gaines had worked on back a number of years ago. We pursued the idea with considerable skepticism on the part of the entomologists as to whether or not diapause control would work. We began looking at the cost, the potential loss, and the potential loss we would take if we didn't do it. We called a few more meetings, and finally wound up over in Lubbock, Tex., one day. The whole Texas A&M staff group, including Dean Patterson, came. We examined the problem to attempt to finally come to some conclusions about what we were going to do. Some of the entomologists were still saying: "Well, we don't know enough about this thing yet. You guys are not organized. It takes very tight control of things for you to do it and there is just not time."

The morning went on and we kept pulling information out of the entomologists as to what could be done if this or that happened, and by noon, I think it was pretty apparent to Dean Patterson that, "by damn, we were going to do it," and that if they were going to help us, they should start giving us some guidelines as to which way we were going to go from there. After lunch we came back and we quit trying to figure out whether or not the diapause program was going to work, and started trying to figure out how to get the diapause program started. As chairman of the meeting at that time, I suggested to the entomologists that they leave it to us to get together the organizational base and to get the money to get it done.

So it was at that meeting that we kicked off, without very much knowledge about the diapause program, and without any organization other than what the Plains Cotton Growers had—though they had made a total commitment to do whatever was necessary. We jumped into that project, and I was delighted to see the gears of the brains of the entomologists in Texas go to work on it, because when they really sat down and started refining this thing, it was only 3 years until we had the weevil within that control zone almost to the point of extinction—a 99-point-something-percent reduction. By about the fourth or fifth year, the farmers in that area said: "We haven't got a boll weevil problem any more. What are you guys carrying this program on for?" But we knew that these figures that E. F. Knipling showed us today could come back on us, so we kept at it, and we continued to carry on the program with considerably reduced cost.

In conclusion, I want to make the observation, as a farmer and as a producer, that there is a heck of a lot at stake on this one.

D. D. HARDEE, Boll Weevil Research Laboratory: We have been involved in a great deal of research at the Boll Weevil Research Laboratory now for 10 or 12 years. I think the record shows that we have had to perform under some very adverse conditions. I agree with the philosophy that an individual can perform a lot better if he is under some pressure, but that way of thinking has its limits. This year in the Pilot Boll Weevil Eradication Experiment we had to come up with the necessary boll weevils—sterile males to release, let us say, on 7,000 acres. We were under a lot of pressure to get that done, and though a lot of folks worked awfully hard, we couldn't do it all of the time.

If I understand properly the proposal before us, in the fall of 1975 we would start a reproduction-diapause program on 800,000 acres out in West Texas, which means that in the spring of 1976 we have to come up with a large number of sterilized boll weevils—male, females, mixed, or whatever. At this particular point, the only boll weevil rearing facility available can handle, at peak production, enough for a maximum of 100,000 acres of cotton, and that is enough for one county in Mississippi—if you don't select the wrong county. How in the world, in 2 years time, can we come up with enough sterile insects? Even if we have the techniques for rearing, even if we have the techniques for sterilizing, how, in 2 years time, are we going to have enough insects to release on 800,000 acres of cotton?

I am not saying that we should not attempt this program. All I am saying is, let's look at the starting point realistically.

B. F. SMITH, Delta Council: I have been somewhat confused about some of the previous comments. Perhaps part of our problem is the word "eradication," which has been bandied about so much. Maybe our problem is a matter of semantics more than anything else, and I wonder if some people see dedication toward eradication as being contrary to philosophies of pest management. Personally, I think we are more or less talking about the same thing, and I don't want to see this meeting end on a discordant note. Too much effort has been put into it.

The Delta Council had a small part in this program in the initial stages. Hugh Arant and I were charged with the responsibility of getting the Mississippi Legislature to appropriate the funds for the rearing facility there. Perhaps you are unfamiliar with the Mississippi Legislature. There are a lot of fine people in it, but there are a lot of people who took a lot of explaining. We took this program down there and talked with the Legislature, and we got it passed in the House and the Senate without a dissenting vote.

But we made one mistake: we didn't ask for enough money. Nobody had ever built one of these facilities before, and when it got pretty far along, we found that we did not have enough money, so we had to go back the next year with our hat in our hand and tell the folks down there that we had come up short. They said, "Don't worry," and appropriated additional money without a dissenting vote.

I think it is important to the program that this conference not end with the appearance that we are going in different directions. I hope that we can arrive at some practical approach with which we can move toward our long-term objective of trying to handle the boll weevil in an effective way.

F. G. MAXWELL, Mississippi State University: As B. F. Smith has pointed out, the Mississippi Legislature was very good to us in providing a research facility to mass-rear boll weevils for the south Mississippi program. I was actively involved in the planning stage during the rearing facility construction. I know the problems involved, and I know the time involved in the construction of a complicated rearing facility such as we have at Mississippi State. But this facility was designed as a research facility, not as a production facility for beltwide eradication. It was designed to do the developmental work and refinement of mass-rearing technology necessary to allow us to project the needs of the two or even three additional rearing plants which would be necessary to produce the numbers of weevils needed to achieve beltwide eradication if and when we attempt it. So, I want to make it perfectly clear that this is a research facility, and that rearing is a limitation on when we could get a program underway.

I have many times emphasized that we have serious limitations in rearing, and that it is going to require major monetary input into research development within the next few years to provide the necessary know-how to mass-rear the weevils that are going to be necessary. How long it will take will depend upon how much money is fed into this research unit to solve the problems that are facing us. So, whether it will take 2 years, 3 years, or 5 years is really going to depend upon the resources, the training, and the manpower put to it. Thus, if we are really serious about beltwide eradication, we are going to have to immediately put resources into rearing and into chemosterilization.

Again, this rearing facility is really a research project in itself, from which we hope to know what to recommend in the way of larger facilities in the future. It does take time to build additional facilities, and this is going to have to be taken into consideration even after we get the necessary information to give to architects and engineers and other people as to what should be included in the rearing facilities.

DAN CLOWER, Louisiana State University: I am an older entomologist, and I am not against getting rid of the boll weevil by any means. I view this as a legitimate objective. My dealings in this matter go back a number of years. In 1955, I had to face growers and tell them I really did not know what they could do to control the boll weevil. That was the year when we encountered resistance in Louisiana, and I hope I never have to face growers in that type of situation again, but our difficulties then are part of the reason for my concern now. I was also associated with the fire ant eradication program in the early stages and when it suddenly began to get out of perspective and switched from a research effort to a premature eradication effort, I went to L. D. Newsom and asked to get out. At that time I predicted that the entomologists, and really the whole profession, would be faced with some very serious problems. Today, there is a very definite difference between the terms "eradication" and "pest management."

I would like to make two other points: First, refering to H. L. Bruer's remark about problems with people, it is going to be difficult or impossible to sell growers on a program when the significant segment of the research entomologists are not convinced at this time that we are ready for it. As for the timetable presented earlier, I think that these problems in technology can be solved. Secondly, I suggest that any decision to proceed, now or in the future, be a professional one and not a socio-political one.

DON ANDERSON, cotton producer, Lubbock, Tex.: I don't think any producers who really understand the problems that entomologists refer to have any illusions about the tremendous undertakings in this program. As a producer I have had considerable experience in many of the various components of the Pilot Boll Weevil Eradication Project. We tested a lot of the phases of the program utilized out in the High Plains region back in years past. It is a very tedious and time consuming job. But without doing something, we can never know success. At some time, sooner or later, the entomologists and the people who guide the producers' thinking need to reconcile their various views, consider what is at stake if we don't get together, and develop some organized system of coping with the insect. And I agree with B. F. Smith that for all the different opinions, we may wind up with the same thing. We possibly have some time before resistance develops; we possibly have some time before many of the insecticides that we can use are banned. We don't know for sure how much time we have before the resolution of petroleum supply problems puts the synthetic people back into strong competition with us. I personally believe that the political environment is right, and that if we can get systems satisfactory to everyone developed and worked into place, we should be well on the road to beginning the project.

CHARLES LINCOLN, member of the Arkansas Plant Board: I also happen to be a working cotton entomologist of some 30-odd years experience. It is my opinion that we do not have the technical competence to eradicate the boll weevil. I come from a State where the boll weevil has already been eliminated as an economic pest. Boll weevil control in Arkansas is at such a level that the insect has a very minor impact on the quality of cotton; the cost is acceptable. But, as a working entomologist from the Plant Board I do have to help make action decisions, and I am generally considered to be an exponent of direct action. If, however, the farmers and politicians want to eradicate the boll weevil, "have at it," but count me out.

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